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An Appraisal of Methods for Salvaging Small--Sawmill Residues in the Southeast

by A. S. Todd, Jr. and

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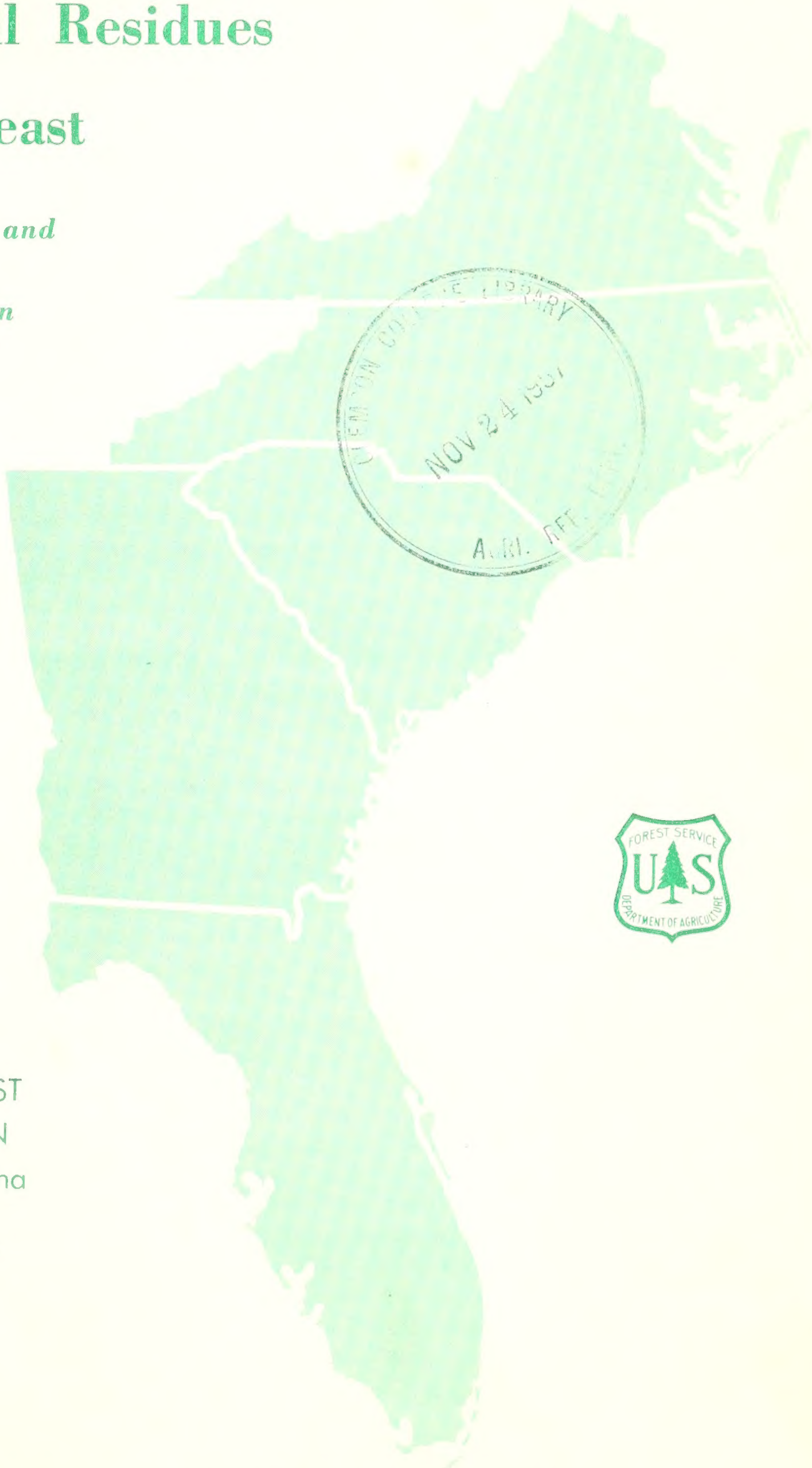

SOUTHEASTERN FOREST
EXPERIMENT STATION
Asheville, North Carolina

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AN APPRAISAL OF METHODS FOR SALVAGING SMALL-SAWMILL RESIDUES IN THE SOUTHEAST

by

A. S. Todd, Jr. and Walter C. Anderson

SUMMARY

Ten possible methods of salvaging pulpable slabs and edging strips from small pine sawmills are presented. A system of cost analysis for determining the cheapest method for a given situation and area is outlined and illustrated.

The various salvage methods are reduced to their component operations such as debarking, chipping, handling, and transportation. Unit cost estimates by volume of output are prepared for each of these components. Summing the component costs in appropriate combinations provides cost estimates for complete salvage methods. In this way, it is possible to determine the lowest cost output of chips for each method and the lowest cost method for any desired output.

Application of the proposed analysis to a typical Piedmont area indicated that the cheapest method of salvaging volumes up to 190 cords per day is by concentrating rough residues at the pulpmill for debarking and chipping. If the volume required exceeds 190 cords, the central operation should be supplemented by rail yards that process rough residues and ship chips to the mill. The smallest economic rail yard is one with a daily capacity of 25 to 30 cords. Although debarking and chipping at centralized points are less expensive than the same operations performed at small sawmills, there may be circumstances under which processing at the sawmill is necessary or desirable. For such cases, the cost analysis showed that if the debarking is to be done at sawmills, money will be saved by chipping the residues there as well.

INTRODUCTION

Sawmill slabs, edging strips, and other residues formerly considered of little or no value are becoming an increasingly important source of wood for pulping in the Southeast. The dollar-per-hour minimum wage and recent increases in the price of roundwood should encourage an even more rapid expansion of the market for wood residues in the near future. However, to date, the development of the slab salvage program has depended primarily on the installation of expensive log barking and chipping equipment at the larger pine sawmills. Little progress has been made in the marketing and utilization of residues at the small pine sawmills that produce three-quarters of all the potentially chippable material.

This report has two purposes. The first is to appraise the practicability and comparative efficiency of various methods for procuring, transporting, and processing the residues in a typical small-mill area. The second is to present a method of cost analysis that can be employed to select for any area the cheapest means of obtaining a desired quantity of pulp chips from small-mill residues.

Since the pulp and paper industry is primarily based on the use of pine, the costs and other data presented herein are intended to apply only to the pine species, pine sawmills, and pine-producing areas of the southern Piedmont. The operating and handling methods described, however, will apply equally well to hardwoods when a market for them develops.

POSSIBLE SALVAGE METHODS

Methods of marketing small-mill residues for pulping can be grouped under two heads: (1) those involving direct shipment to a pulpmill, and (2) those involving assembly and reshipment, with varying amounts of processing, at concentration points located in the lumber (and slab) producing areas. At one time or another, both rough and hand-peeled slabs have been shipped directly to pulpmills in this region. Direct dealing between sawmill and pulpmill also characterizes the marketing of pulp chips produced at the larger sawmills. Concentration yards play a prominent role in the procurement of round pulpwood and the manufacture of lumber, so they may also prove successful in facilitating the procurement of slabwood.

Sawmill residues originate as irregularly shaped pieces in a variety of widths, thicknesses, and lengths. In the rough form, their average bark content ranges from approximately 25 percent by volume for edgings to about 35 percent for slabs. To prepare the residues for pulping, the bark must be reduced to 5 percent or less, and they must be converted to chips of rather uniform length, conforming to the specifications of the purchaser.

With machines now on the market, it is possible to remove the bark either from the logs before sawing or from the slabs and edgings afterwards. If slab barkers are employed, they can be installed at the sawmills, at concentration yards, or at the pulpmill. Chipping offers a similar choice of locations. The sites selected for debarking and chipping should be determined chiefly by the volumes to be handled; by balancing the cost of transporting bark against the greater efficiency of large-scale centralized processing; and by comparing the costs of loading, transporting, and unloading slabs with the same costs for chips.

Based on the alternatives just outlined, there are apparently ten possible methods of salvaging small-mill residues for pulping, as follows:

Direct Shipment from Sawmill to Pulpmill

1. Rough slabs and edgings
2. Slabs and edgings from debarked logs
3. Peeled slabs and edgings
4. Chips from the slabs and edgings of debarked logs
5. Chips from peeled slabs and edgings

Assembly and Reshipment at a Concentration Yard

6. Slabs and edgings, or chips, reshipped in the same form as received
7. Slabs and edgings peeled at yard, chipped at pulpmill
8. Slabs and edgings peeled and chipped at yard
9. Slabs and edgings from debarked logs chipped at yard
10. Slabs and edgings peeled at sawmill, chipped at yard

Economic considerations aside, all these methods are practicable with the bark peeling and chipping equipment now available. There is also a chance of expanding the list if it becomes feasible to remove bark after chipping as well as before. Experiments with hammermills, air and liquid flotation, and centrifugal separators offer promise, but, to date, results with southern pine have not been fully satisfactory.

ESTIMATING THE EFFICIENCY OF SALVAGE METHODS

If all the ten salvage methods for which suitable equipment is now available were in use today, their relative efficiencies could be measured in terms of the cost of chips delivered to pulpmills. Unfortunately, only a few of them are in use, and their period of operation has been too brief to provide much data. Lacking sufficient actual operations to study, we have attempted to predict the prospective efficiencies by evaluating the various factors that would determine chip cost.

Of the factors affecting efficiency, some, such as residue output rates, concentrations, and selling prices, were investigated by area surveys.[1/] Others, such as dimensions of slabs and edgings, their wood content in terms of volume and weight, and the proportion of bark, were sampled at sawmills.[2/] Data on machine prices, performance characteristics, production rates, labor and power requirements, maintenance costs, and the like were obtained from machine manufacturers and users. Labor costs other than for machine tending were measured by time studies. This left only truck and rail transportation costs, which could be derived largely from published material.

1/ Todd, A.S., Jr. Sawmill and logging residues in the South Carolina Piedmont. Southeast. Forest Expt. Sta. Paper 31, 32 pp., illus. 1953.

2/ Todd, A.S., Jr. and Anderson, W.C. Size, volume, and weight of pine slabs and edgings in the South Carolina Piedmont. Southeast. Forest Expt. Sta. Paper 49, 21 pp., illus. 1955.

For convenience in costing, all the salvage methods were reduced to their common operational components, namely: (1) debarking, (2) chipping, (3) handling, and (4) truck and rail transportation (including loading and unloading). Cost estimates were prepared for each of these components. The component costs were then combined with residue price information so that the unit cost of bark-free chips at various levels of output could be calculated under each method of salvage. From the results, it was possible to determine the lowest cost output for each method and, conversely, the lowest cost method for any output.

VOLUME-WEIGHT CONVERSIONS

Most of the costs in the body of this report are per 128 cubic-foot cord of bark-free slabs or per "unit" of unscreened chips. On the average, a bark-free cord of freshly-cut pine slabs in the Piedmont will contain 79 cubic feet of wood weighing 5,000 pounds. A unit of unscreened chips is defined as the quantity produced from a cord of bark-free slabs. Thus, it too weighs 5,000 pounds.

Consequently, to convert any cost per bark-free cord or per unit of chips to an equivalent cost per thousand pounds, divide it by 5. To convert volume in cords or units to thousands of pounds, multiply by 5.

COMPONENT COSTS

The per-cord costs in the following pages are approximations of the actual costs that might be experienced in procuring, transporting, and processing various quantities of slabs and edgings from the small sawmills of a typical Piedmont area. The accompanying text and the appendix show how they were derived. The presentation will enable a reader to follow the development of cost estimates, judge their reasonableness, and substitute data of his own wherever he pleases in the computations.

Price of Slabs and Edgings at the Sawmill Sites

The greater part of the slabs and edgings produced at small pine sawmills are neither salable nor needed for fuel. In some cases, the unwanted residues are burned, but danger of the fire restricts this practice to certain locations and seasons. More commonly, the residues just accumulate.

To the landowner, the rotting piles of worthless material are an eyesore, a fire hazard, and a waste of the land they occupy. To the sawmill operator, they are a nuisance and represent an unproductive use of the labor required to build them. Landowner and sawmill operator alike might be better off if the residues were not piled at all but were given away as fast as they came from the saw.

The cost of piling is substantial. The average portable sawmill devotes about $1\frac{1}{4}$ man-hours per thousand board-feet to waste disposal. Nearly half of this time would be saved if the slabs and edgings could be loaded on trucks, trailers, or pallets rather than piled. At a typical 8,000 board-foot-a-day mill, 50 percent of one man's time would be freed for increased production. The authors estimate that as much as $8 a day might be added to the net income of the operation in this way.

For the reasons just discussed, one-half to three-quarters of the residues produced at small pine sawmills have zero or even negative value. Consequently, it seems probable that anyone wishing to procure a small quantity of rough slabs or edging strips could do so merely by hauling them away. However, in most parts of the Southeast, a procurement program of any size would involve competition with the already existing demand for fuel. A survey of a typical area in the South Carolina Piedmont reveals the extent of the fuelwood market and the current market value of residues (table 1). This area supports a predominantly rural population of 50 persons per square mile. Output of slabs and edgings is roughly 20 standard cords per square mile per year. How this output compares with that of other areas of the Southeast is shown in figure 1.

Table 1.--Proportion of sawmill residues available at various prices

Price per cord (Dollars)	Quantity
	Percent of total
(1/)	64
0.25	69
.50	73
.75	77
1.00	81
1.50	87
2.00	93
2.50	98
2.75	100

1/ No value.

The values in table 1 are for rough residues at the mill site before processing of any kind. Volumes unused or given away are considered valueless; volumes consumed by landowners and sawmill hands have been assigned values based on the prices reported for actual sales of fuelwood. The quantity percents are cumulative, so each represents the quantity presumably available at the stated price or less.

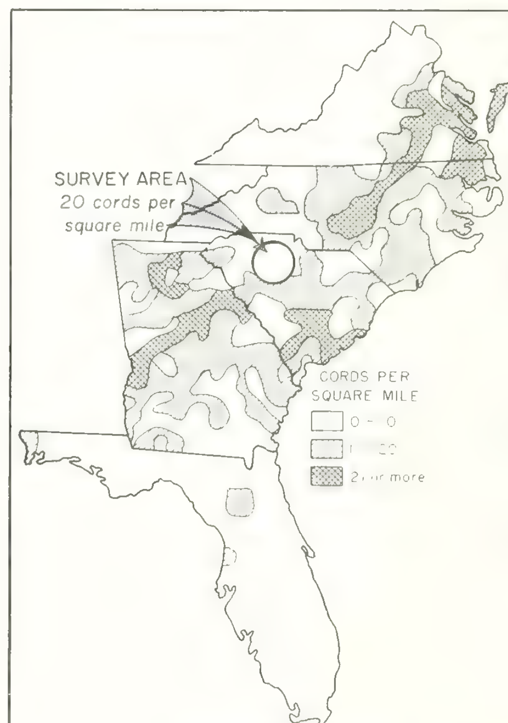


Figure 1.--Annual output of pine sawmill residues in the survey area and elsewhere in the Southeast.

Cost of Trucking Sawmill Residues

So much for the market value of slabs and edgings at the sawmills. By offering the equivalent of contract hauling charges (and thus a profit) for delivered residues, a small volume might be obtained without the necessity of owning or hiring trucks. Current trucking rates for slabs and edgings (and also for chips) are approximately as shown in table 2.

Table 2.--Contract trucking charges for sawmill residues and chips 1/

One-way distance (Miles)	Rough slabs & edgings 2/	Bark-free slabs & edgings	Chips
	Dollars per cord	Dollars per cord	Dollars per unit
5	2.20	2.60	--
10	2.80	3.30	--
15	3.40	4.00	--
20	3.90	4.60	--
25	4.40	5.20	2.50
30	4.90	5.80	3.00
40	5.50	6.50	3.80
50	6.10	7.20	4.40
60	6.50	7.70	4.80
70	6.90	8.10	5.10

1/ Based on charges for residues and green pine lumber reported by a number of southeastern firms.

2/ For cost per bark-free cord of trucking "barky" residues, multiply these values by 1.5.

The charges presented are based on the assumption that slabs will be hauled up to 30 miles by truck, averaging 3 cords per trip, and beyond 30 miles by semi-trailer, averaging 6 cords per trip. The chip charges are based on the use of semi-trailers carrying 7 "units," a unit being defined as the volume of chips produced from a cord of bark-free slabs. Included in the slab rates are an allowance for time spent hand-loading at the sawmill and dump or power unloading at destination. It is assumed that chips will be loaded by gravity or blower and unloaded by dumping or power methods.

Delivered Cost of Sawmill Residues

Combining the information of tables 1 and 2 provides estimates of the delivered cost of slabs and edgings in our typical Piedmont area (fig. 2).

The prices in table 1 and figure 2 are minimum prices. In the first place, they are based on the assumption that fuelwood buyers will pay no more than present prices for residues, so that slabs and edgings can be diverted from fuel use by slightly higher bids. However, since practically two-thirds of the residues produced are now unsalable at any price, the

price-quantity relationships indicated in table 1 may not reflect the true demand for fuelwood. Secondly, it is probably erroneous to assume that all owners of residues presently unsalable would be willing to give them away. Actually, if potential buyers appeared, they would find that some owners had minimum prices below which they would refuse to sell. Thirdly, the prices would apply only so long as a surplus of residues existed.

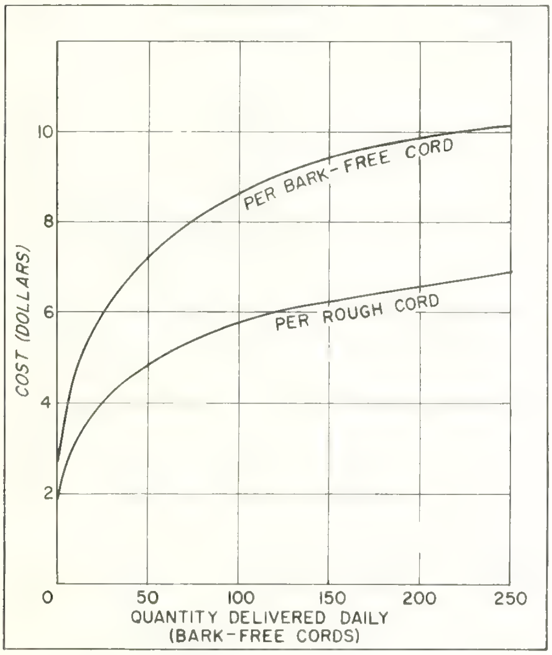


Figure 2.--Cost of barky residues, per cord, delivered to a Piedmont point.

The first of these qualifications is of little practical significance. Even in the unlikely event that fuelwood consumers refused to be outbid and other buyers were forced to draw entirely from the surplus residues not needed for fuel, the rise in delivered price would amount to less than 25 cents per cord. The second qualification, that owners of surplus residues might be unwilling to give them away, is not too important either. With no other market for their residues, owners may have to be content with a nominal price.

The third and last qualification is potentially more important. The prices in table 1 and figure 2 reflect the fact that the slabwood market currently absorbs only about one-third of the output. Superimposing a new demand on top of the existing demand for fuelwood will tend to reduce the surplus. Nevertheless, as long as untapped sources of slabs can be drawn upon by expanding the procurement territory, sellers will be powerless to force the price upward. Since anything approaching full utilization of sawmill residues is probably years away, the prices of table 1 and figure 2 will be used in this report.

Debarking Costs

At the present time, there are more than 100 log-barker installations in the South. Most of these are at the larger pine sawmills. As a result, the advantages of whole-log debarking are fairly well established. From a conservation standpoint, the most important feature of a debarked log is that practically every bit of solid waste produced in sawing it is easily salvable for chipping. In addition, a sawyer can do a better job on a clean log, with the result that the lumber out-turn is greater both in total and in proportion of upper grades. Supplementary benefits are a marked saving in saw maintenance, less "down time" while saws are being filed or changed, and a cleaner sawmill. For these reasons, the installation of log barkers often results in 10 to 15 percent increases in lumber production rates.

Small sawmills could presumably reap the same benefits from log barking. At present, however, there is no log barker fully suited to small-mill use. Existing equipment is too large, too heavy, or too expensive.

The design of log barkers is still in a state of flux. Among the current models are machines using chain flails, cutter-heads, hydraulic pressure, and concentric rings of debarking tools. They employ a variety of feed works, and vary widely in their capacities, power requirements, and the number of men required to operate them. Consequently, it is impossible to generalize on the subject of log debarking costs. About all that can be concluded is that the mean daily cost (including the operators' wages but excluding power) of owning and operating a log barker is about $44 when it is operated at capacity. Of course, individual models may vary considerably from this figure.

A barker at a typical 8,000 board-feet-per-day sawmill would operate at only a fraction of capacity. Consequently, it could probably operate with one less man than would be needed at full capacity. Making this adjustment and adding in the cost of a suitable gasoline power unit gives an estimated daily cost of $39.

If we assume that the production of an 8,000 board-foot sawmill would be increased 10 percent by the installation of a log barker, the resulting output would be 8,800 board-feet of lumber and approximately 5.3 cords (bark-free basis) of slabs and edgings per day. Charging $39 of debarking cost to 5.3 cords of chippable material results in a mean cost of $7.35 per cord. Under present conditions, the extra 800 board-feet of lumber and reduced saw maintenance would add an amount to lumber operating profit equivalent to about $3.10 per cord. Deducting this from $7.35 leaves a balance of $4.25 per cord directly chargeable to the bark-free slabs and edgings.

The alternative to whole log debarking is to debark the slabs and edgings, and there are a number of machines for this purpose. They range from small, hand-fed, cutter-head models to hydraulic models with automatic feed, capable of debarking 200 or more cords per day. As might be expected, the highest-priced machines require the least manpower per unit of output. When both machine cost and operator's wages are taken into account, slab barkers show an apparent trend toward greater efficiency with increasing size (fig. 3). As given, the costs include operators' wages but no allowance for a power source. Costs of owning and operating gasoline and diesel power units and electric motors are presented elsewhere.

It will be noted that there is a break in the per-cord cost curve for slab barkers. This break results from the fact that no commercial machines are yet available in the 20 to 60 cords-per-day capacity range. All the mechanical models, as represented by the sharply declining and curved first segment of the chart, fall below this range; all the hydraulics, as represented by the smoothly curved last segment, are above it. Cost calculations which include the cost of power indicate that for outputs of 20 to 55 cords per day it is cheaper to add mechanical units than to employ a hydraulic barker at partial capacity. This use of multiple units is represented by the horizontal, straight-line portion of the curve in figure 3.

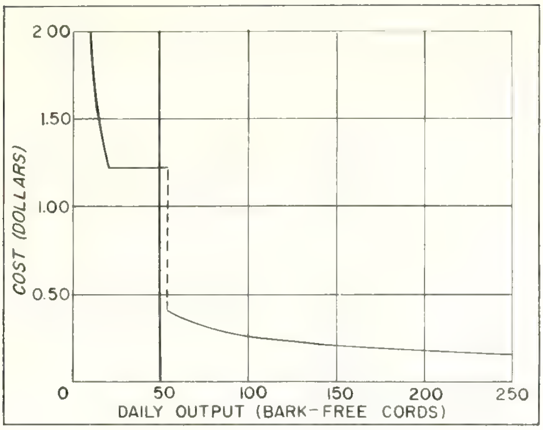


Figure 3.--Cost per bark-free cord of operating slab barker.

In discussing log barkers, we mentioned that the installation of one at a sawmill could be expected to boost lumber production 10 percent or more and reduce the cost of saw maintenance. Slab barkers do not produce collateral benefits of this kind. Consequently, the entire cost of owning and operating them is a charge against the bark-free slabs and edgings produced.

Since slab barkers contribute nothing to the lumber operation, there is no necessity of locating them at sawmills. Of course, transportation savings will result from eliminating the bark weight at the source. On the other hand, debarking at a pulpmill or slab concentration point permits closer quality control and economies of large-scale operation.

Hand debarking, either of logs or slabs, will not be considered here. It is too wasteful of manpower. Also, buyers of pulpwood, poles, and other products which were once peeled by hand in the woods report that men willing to do this type of work are almost impossible to find.

Chipper Costs

Slab chippers sell for a wide range of prices. The costs presented in this report (fig. 4) are for a line of 6-knife, overhead-discharge chippers manufactured and extensively used as waste-wood chippers in the South. These costs are for the chipper alone; power and labor are additional.

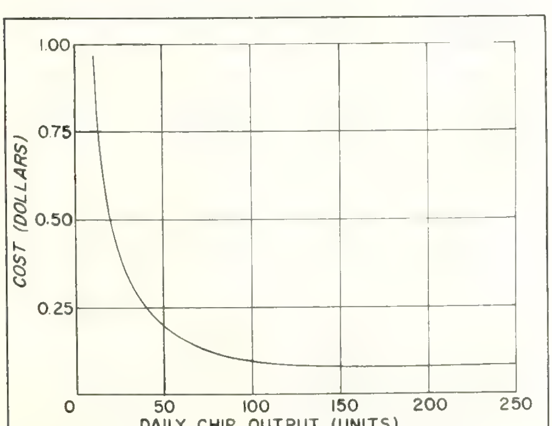


Figure 4.--Cost of operating slab chipper, per unit of unscreened chips.

Like slab barkers, chippers could be installed at sawmills, at concentration points, or at the pulpmill. However, even the smallest chippers could process the full slab output of most small sawmills in an hour per day. Consequently, if chipping is to be done at the mill sites, it might be more efficient to employ portable equipment that could be moved periodically to accumulation of slabs.

Materials Handling Costs

If debarking or debarking and chipping are performed at small sawmills, the volume of material to be handled is not great enough to justify powered conveyors. Ordinary roll tables such as are used to remove lumber from the saw will suffice for slabs, and chippers can be fitted with vanes to blow chips into trucks or other vehicles. However, if the processing is to be done in quantity at a central location, mechanized handling is probably a must. The equipment for this purpose might consist of a crane or fork-lift truck to unload the incoming slabs, belt or chain conveyors to move slabs and bark, and either belt or pneumatic conveyors for the chips.

For the purposes of this report, three types of slab processing plants can be considered. The first is merely a debarking plant that receives barky slabs and turns them out bark-free. The second receives slabs already debarked and reduces them to chips. The third is an integrated plant that both debarks and chips. The conveyor needs of the first type would be satisfied by two short, flat belts, one leading to the slab barker and one from the barker to a truck or railroad car, plus a drag chain to convey bark and scraps to the refuse burner. The needs of a chipping plant would be even simpler, since chipping produces very little refuse. However, a chipping plant of any size would ordinarily require some sort of chip storage bin or silo and, if the output is to be shipped by rail, pneumatic loading or use of a car shaker would insure greater compaction and weight per car than plain gravity loading.

The conveyor needs of an integrated debarking and chipping plant are essentially a combination of those just described for the nonintegrated operations. In addition, every plant would require facilities for unloading slabs from trucks. In some cases, a simple hand hoist might be sufficient. At larger capacity plants, the need for maintaining a yard inventory of residues would make a mobile crane or fork-lift truck essential. Figure 5 shows the estimated per-cord cost (excluding power and labor) of handling materials at each of the types of plants mentioned.

Power Costs

All the machine costs discussed above, except those for log barkers, are exclusive of power. The average horsepower requirements of various types and sizes of machines used at slab processing installations are shown in the appendix on pages 30 and 31. Page 33 shows the cost of owning and operating electric motors. The kilowatt-hour rates for electricity (page 34) are those currently charged by a North Carolina power company. Translated

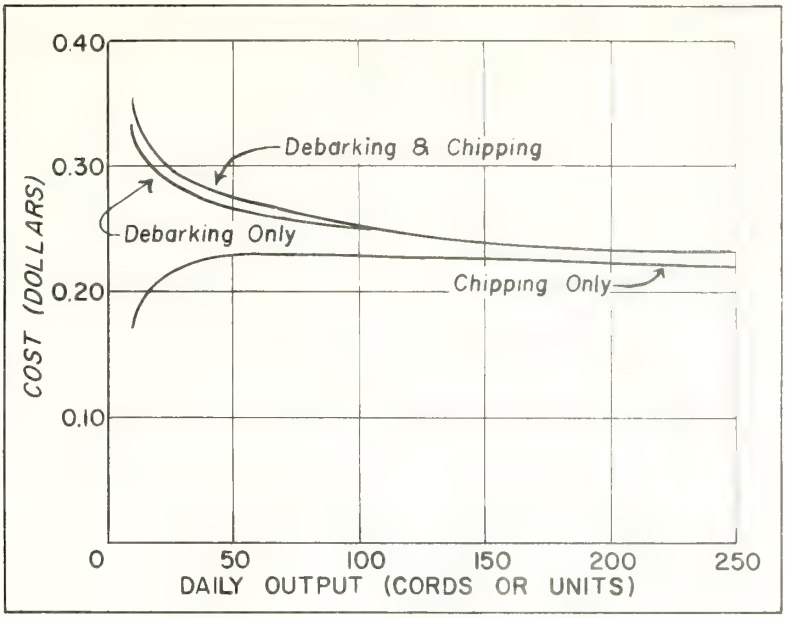


Figure 5.--Cost per bark-free cord (or unit of unscreened chips) of operating conveyors, etc. at three types of processing installations.

to a per-cord basis, the costs of providing electric power for debarking, chipping, and integrated plants are shown in figure 6. For the sake of simplicity, we have omitted a similar chart for gasoline and diesel power, but the necessary cost data will be found on page 35.

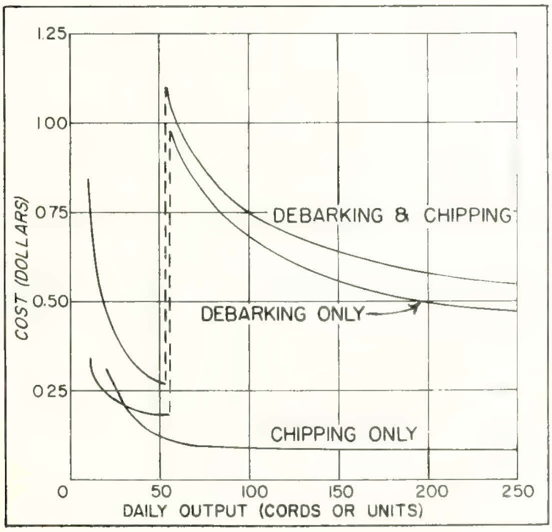


Figure 6.--Cost per bark-free cord (or unit of unscreened chips) of electricity to power three types of processing installations.

Labor Costs

Readers of the preceding pages may have wondered why debarking costs included operators' wages, while wages were left out of all other processing costs. The explanation lies in the nature of the machines involved. Chippers and conveyors are automatic machines. When properly combined, they require human attention only for maintenance and in the event of jamming. A slab barker, on the other hand, commands the full-time services of one or more men as long as it is operating. Furthermore, the degree of automation built into a barker does not necessarily determine its production rate. In the same capacity class one can find high-priced semi-automatic machines and lower-priced machines with high labor requirements. Consequently, cost can be related to capacity only when the operators' wages are included.

The amount of manpower allowed for in computing barker costs was based on manufacturers' recommendations and users' experience. Unfortunately, it is not possible to estimate the manpower requirements of complete slab processing plants with the same assurance. Therefore, figure 7 is presented with no claims as to its accuracy. However, the values appear to be in line with crew organizations observed at several barker-chipper operations.

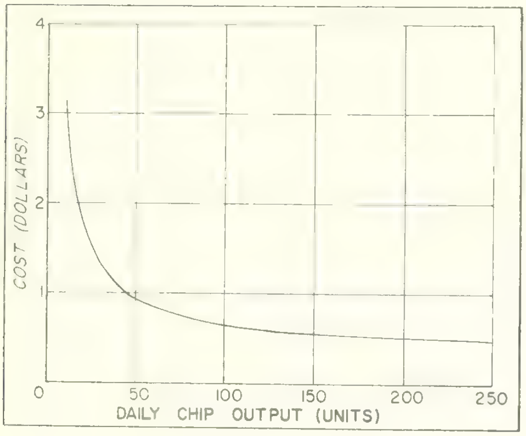


Figure 7.--Cost of labor per unit of unscreened chips, to operate a processing installation (exclusive of barker operators).

Rail Freight

The costs of trucking residues and chips from sawmills were discussed in an earlier section and summarized in table 2. In most cases, truck transportation is the only practicable method of moving the material from a small sawmill to its first destination. Nevertheless, rail freight is likely to be cheaper for the longer distances, and particularly for reshipments from concentration points.

As yet, there are no rail rate schedules for sawmill residues or chips in this part of the country. However, local chip rates have been established for point-to-point shipments in many places. These rates were individually determined and vary somewhat for a given mileage, but the values in table 3 are about average. The slab and edging rates in the table are based on the assumption that when a schedule is established, it will follow the existing schedule for pulpwood, as was the case in the West.

COSTS OF COMPLETE SALVAGE METHODS

There are 10 salvage methods to be considered (see page 3). A pulpmill requiring only a limited volume of residues from small sawmills would presumably select one or more of the first five methods. The residues, whether rough or bark-free or in the form of chips, would be trucked directly to the pulpmill from sawmills in the vicinity. However, with increasing residue requirements and the need to draw from more and more distant sawmills, a point will be reached where one of the second five methods will be more economical. Similarly, if the requirements continue to increase after a concentration yard has been established, it will eventually become more economical to establish a second yard than to extend the drawing territory of

the first any farther. Of course, if the debarking and chipping are to be done either at the sawmill or at the pulpmill (Method 6), yards are not an absolute necessity. Residues can be transferred from trucks to railroad cars at sidings near the points of origin.

Costs of Methods Involving Direct Shipment

Where rough slabs and edgings are to be delivered to a pulpmill (Method 1), their cost upon arrival consists of the purchase price of the residues and the trucking charge. The delivered cost of rough residues both per rough cord and per bark-free cord was estimated in figure 2. The costs per bark-free cord from figure 2 form the bottom curve of figure 8.

The curves in figure 8 show how the cost components can be combined to arrive at the average cost curve for a complete salvage method, in this case Method 1. They also indicate the shape of the problem posed by the economics of residue salvage at small sawmills.

Table 3.--Rail freight charges for sawmill residues and chips [1]

Distance (Miles)	Rough slabs and edgings [2]	Bark-free slabs and edgings	Chips
	- - - Dollars per cord - -		Dollars per unit
50	2.10	2.50	2.60
60	2.30	2.70	2.80
70	2.40	2.80	2.90
80	2.50	2.90	3.00
90	2.60	3.10	3.20
100	2.80	3.20	3.30
120	3.00	3.50	3.60
140	3.30	3.80	3.90
160	3.50	4.10	4.20
180	3.80	4.40	4.50
200	4.00	4.70	4.80
220	4.30	5.00	5.20
240	4.50	5.30	5.50
260	4.80	5.60	5.80
280	5.00	5.90	6.10
300	5.30	6.20	6.40

1/ Includes 3 percent Federal tax.

2/ In this case freight is being paid on bark. That is to say, the charge for transporting wood and bark has to be borne by wood alone. To find this cost per bark-free cord for shipping "barky" residues, multiply values given in the column by 1.5.

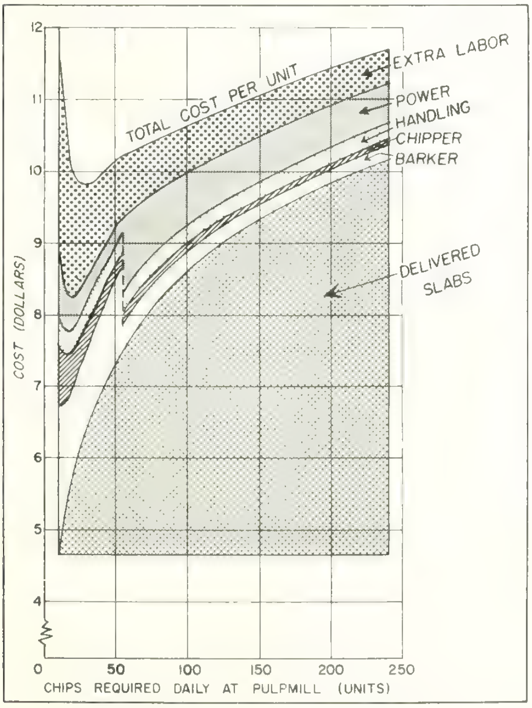


Figure 8.--Cost per unit of unscreened chips when rough slabs and edgings are trucked directly from sawmill to pulpmill and processed at the pulpmill.

For instance, the curves show that average processing costs are high when the volume of material handled is low, and that they decline rapidly at first as the volume increases, then at a less rapid rate, finally stabilizing at a near-constant figure. The delivered cost of slabs, on the other hand, is low at the smallest volume and rises rapidly (but at a declining rate) as the volume increases. Thus, volume has opposite effects on the cost of the residues and on the cost of processing them. However, the two are never compensating; processing is the more critical item at volumes up to 25 units per day, and slab cost at volumes above that.

In the discussion of slab debarking, attention was called to the break in the average cost curve at the point where hydraulic equipment replaces mechanical machines. This break shows up in figure 8. However, note that the addition of power results in a fairly smooth curve for total per-cord debarking cost.

As one alternative to delivering rough slabs, a log or slab barker could be installed at the sawmill, and bark-free slabs could be delivered to the pulpmill (Methods 2 and 3, respectively). Another alternative is to install a chipper as well as debarking machinery at the sawmill, and deliver chips to the pulpmill (Methods 4 and 5).

Figure 9A shows the cost of chips produced by each of these five methods. Curve 1 corresponds to the top or total average cost curve of figure 8. The other curves were obtained in the same fashion by summing the appropriate cost components. The costs of Methods 2 through 5, which require processing of residues at sawmills, are based on a typical small-mill capacity of 8,000 board-feet per day. Costs of processing would be less at larger sawmills and somewhat more at smaller ones.

Method 1, which involves the delivery of rough residues and centralizes debarking and chipping at the pulpmill, is the cheapest. It can produce chips for 50 to 75 cents less per unit than any other method, except when the quantity handled is very small. Methods 2 and 4, which involve log debarking at sawmills, are next, while Methods 3 and 5, which call for slab debarking at sawmills are the most expensive.

In practice, the cost advantage of Method 1 over the others would usually be greater than shown, because the costs shown here for Methods 2 through 5 include no margin for profit and risk on the debarking or chipping operations. Therefore, these costs actually apply only to the specialized case of a pulpmill maintaining and operating barkers and chippers at sawmills.

Since the most economical method is the one that avoids any processing at sawmills, it may seem paradoxical that the next best method is one that requires all processing to be done at the sawmills. Apparently the explanation is that chipping is an inexpensive operation, while the subsequent cost of handling and transporting chips is much smaller than for slabwood.

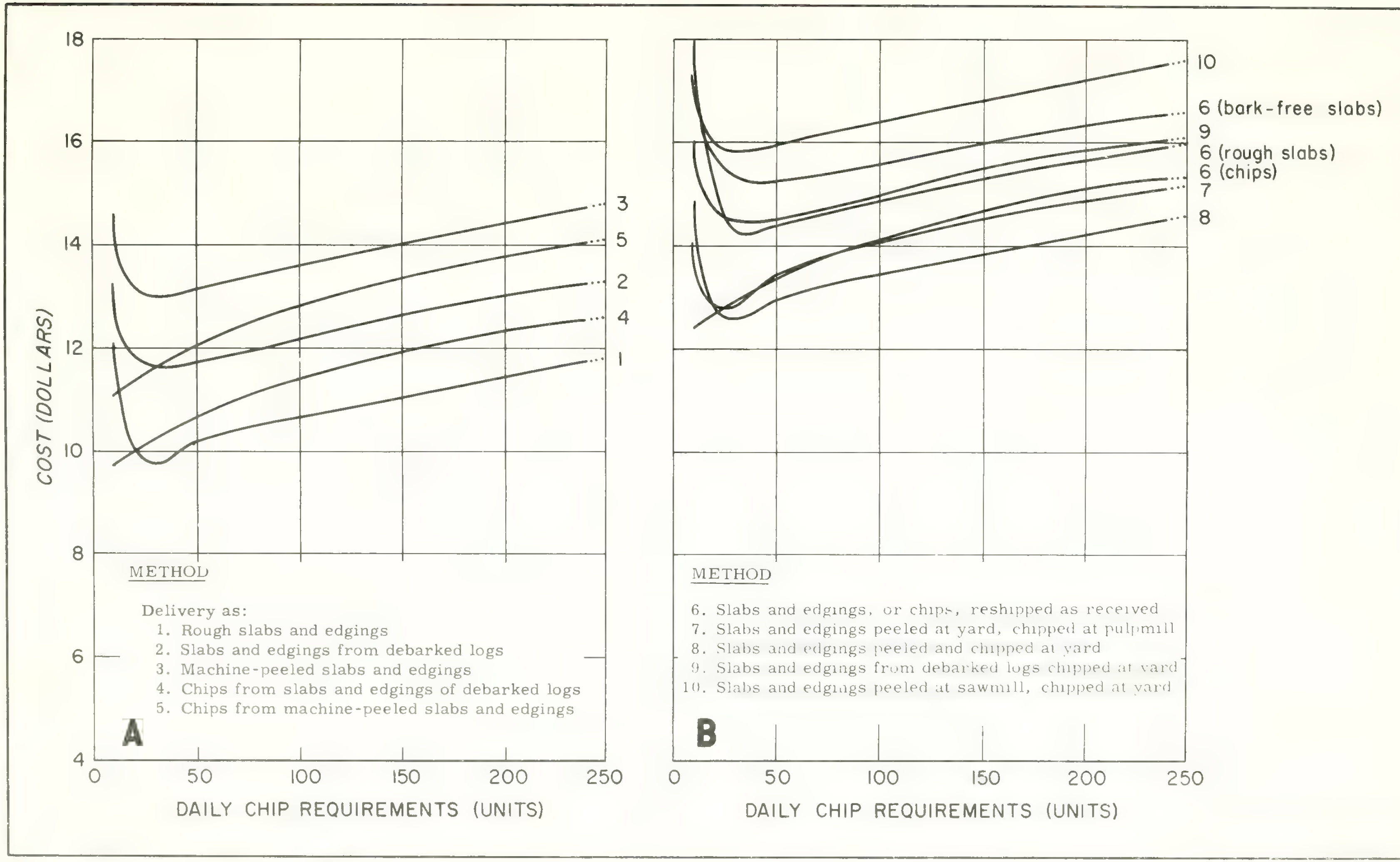


Figure 9.--Cost of unscreened chips per unit at pulpmill by ten salvage methods. A, When material is trucked from sawmill directly to pulpmill. B, When material is trucked from sawmill to concentration yard and reshipped by rail to pulpmill.

In discussing the components of the Method 1 cost (fig. 8), it was noted that slab cost increased with volume, while processing cost decreased. To a lesser extent this is also true of Methods 2 and 3. The result is that each of these methods attains maximum efficiency at some level of production. For Method 1, average chip cost is minimized when production is 30 units daily. It is minimized for Methods 2 and 3 at a point between 30 and 40 units.

Methods 4 and 5 are different in this respect. Average cost increases with quantity throughout the range of values calculated. The reason is that all the processing of residues under these methods is performed at sawmills of relatively fixed capacity. For all practical purposes, the volume of chips procured by a pulpmill can be changed only by varying the number of sawmills from which chips are obtained. The output per sawmill and, therefore, the processing cost do not vary. Thus, the constantly rising cost curves for Methods 4 and 5 are a reflection of the need to haul from more and more distant sawmills and to pay more for slabs from sawmills nearby as chip requirements increase.

Costs of Methods Involving Rail Shipment from Concentration Points

Few small sawmills are located on railroad sidings. In the Southeast, most small mills are portables that operate in the woods. For this reason, the bulk of the residues would have to be moved to their first destination by truck. The size and weight of these trucks would be limited by the need to negotiate crude woods roads and to maneuver in cramped space. Loaded with heavy, low-value wood residues, their economic hauling radius would consequently be rather short. Comparison of tables 2 and 3 will show that as the procurement territory of a pulpmill expands, it eventually becomes cheaper to transfer loads from trucks to railroad cars than to transport them all the way by truck.

The transfer of slabwood from truck to car could be performed at any nearby siding. If the material were bundled and a hoist available, the loads could be transferred to gondolas or flatcars at reasonable expense. However, hand reloading would mean assigning two or more men to the truck and probably could not be accomplished for much less than $2 per cord. Chip reloading would, of course, require specialized equipment. Another objection to decentralized loading is the bother and uncertainty of arranging for the spotting of cars at the right places and times. Some of these difficulties can be avoided by establishing rail concentration yards.

In its simplest form, a concentration yard might merely provide power loading machinery and reship slabs and chips in the same form as they were received. On the other hand, there is an opportunity to process slabs as well as load, thereby reducing the cost of the loading or the rail freight or both.

Figure 9 also shows the cost at destination of chips produced by each of five salvage methods involving concentration yards (Methods 6 through 10). Method 6, yard reshipment in the same form as received, is represented by three curves corresponding to the three forms (rough slabs, bark-free slabs, and chips) in which the residues might be received. For the sake of comparability, all seven cost curves in figure 9B are based on a 60-mile rail haul from yard to pulpmill. The costs do not include any provision for general administration, real estate taxes, or depreciation of buildings and other improvements.

Method 8, calling for debarking and chipping at the yard, apparently costs least at all but the smallest volumes of output. Next in order of economy are Methods 7 (debarking at yard, chipping at pulpmill) and 6 (all processing at the sawmill). The high-cost methods here are those involving slab debarking at sawmills, just as they were among the direct-shipment methods. But, here again, it appears that if any processing is to be done at the sawmills, it should all be done there. Even more important, yard processing results in lower-cost chips than processing at destination (pulpmill).

The High Cost of Processing at Sawmills

The finding that sawmill processing makes for expensive chips is perhaps worthy of further comment. Since rough slabs are one-third bark, and bark has no present value except for fuel, it would seem that bark should be removed as near the source as possible, i.e., at the sawmill. Since chipping permits cheaper handling of residues, it appears that chipping should also take place as near the source as possible. Yet, the cost curves of figure 9 indicate that more economical chips will result from deferring the debarking and chipping until the residues reach their first destination.

The explanation for the high cost of sawmill processing has been touched on before. Chief among the difficulties is the lack of efficient barkers for mills in the 8,000 board-feet-per-day class. Log barkers now in production are too large and too expensive, and slab barkers are either large and expensive or require too much labor. Even the smallest chippers possess considerable excess capacity for mills of this size, but their use would still be feasible if the bark could be removed economically.

In this connection, whole-log barkers show up better costwise than slab barkers for sawmill installation. The explanation, of course, is that a substantial portion of the cost of debarking logs is covered by the increased lumber production possible from peeled logs. At sawmills larger than those considered here, the added lumber income may be sufficient to bear the entire cost of barker operation.

ORGANIZING PROCUREMENT FOR LOWEST COST

At the present stage of machine development, the lowest-cost chips that can be produced from small-sawmill residues would be those from slab barker and chipper installations at pulpmills (Method 1). These central installations could be supplemented as needed by rail yards which would also debark and chip rough residues delivered to them (Method 8). Any other procurement system would result in higher costs.

In planning procurement by the methods just outlined, perhaps the most important decisions are those regarding the lowest cost combination of a central installation and tributary yards. Up to a point, the central installation is the most economical source of chips. However, as chip requirements expand, it becomes necessary to truck slabs from greater distances and to outbid fuel buyers for an ever larger share of the material closer in. In the early stages, the increasing cost of delivered residues is more than compensated by the greater efficiency of large-scale debarking and chipping operations. Reference to Curve 1 of figure 9 indicates that the net effect is a declining cost per unit of chips until requirements reach 30 units a day. The average cost of $9.80 per unit at 30 units is the lowest cost at which it is presently possible to produce chips in our representative Piedmont area (fig. 1). Therefore, until requirements exceed 30 units, there is no economic incentive to establish supplementary rail yards.

It may be recalled that the sawmills of our Piedmont study area produce roughly 20 cords of residues per square mile per year. What would the minimum cost points be in areas with greater or lesser concentrations of residues? It may also be recalled that nearly two-thirds of the residues in the study area have no current market value and that the top price of slabs for fuel is $2.75. What would the minimum cost points be in areas of higher and lower prices? The answer is that, for all practical purposes, the minimum cost point can be considered to be fixed for each salvage method and independent of both residue concentration and residue price.

Determining the optimum (minimum cost) combination of central and rail yards involves two decisions. The first is, when should supplementary yards be established? How large should the central yard be allowed to grow before a rail yard is put in? Then, how large should these two yards become before a second, more distant, rail yard is justified?

Once the need for a supplementary yard or yards has been demonstrated, a second decision is necessary. How should a given volume of chip production be apportioned to minimize the per-unit cost? In other words, how large should each of the yards be?

The question when to add yards and what size to make them can be answered by analyzing the costs, as follows:

When the quantity of chips processed at a central yard or rail yard is increased, each succeeding unit of chips will cost more than the one preceding it. At any level of output, say 50 units per yard, the cost of chips from a rail yard will exceed the cost of chips from the central yard by the amount of rail freight, assuming residue concentrations and prices to be uniform. However, as central yard output expands and becomes more expensive, a point will be reached where the cost of any further output will be greater than the cost, including freight, of obtaining it from a small supplementary yard. To be specific, this point is reached when the cost of the last unit of central-yard chips (marginal cost) equals the average cost of chips from some size of rail yard.

So much for the question of additional yards. How should the total volume of desired output be apportioned to yards? This can be determined by equating marginal costs. From the discussion of the preceding paragraph, it follows that for any level of output at the central yard there is a lower output at the rail yard of such a magnitude that the cost of the last unit, including freight, equals the cost of the last unit produced at the central yard. The outputs at central and rail yard which bring the costs of the last units (marginal costs) into balance represent the minimum cost division of that total quantity of output between yards. Any other allocation of the same total output would result in higher total cost.

What has been said here with regard to a single rail yard of course applies to any number of equidistant yards. If a marginal analysis indicated that a 35-unit rail yard should be established, for example, this would be justification for a ring of as many 35-unit yards as the layout of railways permitted.

Once a yard or ring of yards has been established, the same procedure can be employed in making decisions as to the establishment of more distant yards or rings of yards. In most cases, this expansion would not need to proceed very far, because the number of potential yard sites ordinarily increases rapidly with distance from the pulpmill.

As a practical demonstration of the methods just outlined for allocating chip production to yards, let us return to our typical Piedmont area. For this area, a 30-unit-per-day yard was found to be the most efficient. Consequently, rail yards cannot be justified until the output of the central yard reaches 30 units. Similarly, once a rail yard has been established, its output should reach 30 units before the installation of more distant rail yards is considered.

One more stipulation is needed--the radial distance from pulpmill to the first rail yard or yards, the distance from first rail yard to second rail yard, etc. Rail freight will be minimized when the perimeters of successive yard drawing territories touch, so this situation will be assumed. It will also be assumed that, since the perimeters of their territories touch, the rail distance between yards is approximately equal to the sum of the radii of the two territories.

Table 4 shows the optimum allocation of various volumes of chip output to yards under the conditions just outlined. Apparently, operations should be restricted to a central yard until output reached 165 units of chips. At that point, a rail yard of 27 units capacity would be justified. Similarly, when output at a rail yard reached 35 units, a second, more-distant rail yard of 27 units capacity would be in order.

Table 4.--Lowest cost allocation of chip production to yards in a Piedmont area
(In units)

Total daily requirements	Yard capacities			
	Central yard	First rail yard 1/	Second rail yard 1/	Third rail yard 1/
50	50	--	--	--
100	100	--	--	--
150	150	--	--	--
192	165	27	--	--
200	170	30	--	--
277	215	35	27	--
300	230	40	30	--
374	262	50	35	27
400	275	55	40	30

1/ Values apply also to each yard of a ring of equidistant yards.

The table column titled "Total daily requirements" contains minimum figures in the sense that these volumes would be produced if it were possible to establish only one rail yard at each distance from the pulpmill. However, pulpmills are located with an eye to easy rail connections. In practice, therefore, two or more rail yards can usually be established at each distance. Naturally, the more compact the procurement area for a given volume of daily chip requirements, the greater the economy of operation. One or two rings of rail yards close in are always preferable costwise to a string of individual yards stretching out into the distance.

As stated earlier, the least-cost capacity of a yard is independent of residue concentration or price. The same is approximately true of the least-cost allocation of output among yards. Therefore, the allocations of table 4 apply to any residue concentration or price, provided the concentration and price are the same for all yard locations. Individual calculations are necessary for situations in which the residue concentration or price varies from one yard to another.

APPENDIX

PREPARATION OF COST ESTIMATES

Most of the average cost curves presented in the text were derived from total daily cost curves. The total curves were constructed by calculating costs for particular outputs and then fitting curves to these points. The curves and the calculations on which they were based are shown in this appendix.

In some instances, the available information did not extend over the full span of outputs we wished to analyzed. This made it necessary to project some of the curves considerably beyond the range of the data. In every such case, the portion of the curve that is extrapolated is shown by a dashed line.

The original data are presented here to enable readers to appraise the costs used and the bases for their calculation. Those who have experience data of their own can calculate costs on the same basis and include them to strengthen a curve, or they can substitute them for all or some of the data presented. Others may wish to modify the calculations by using different depreciation periods or investment rates.

All investments and costs were calculated on a uniform basis so that resulting cost components could be combined. In calculating investment in equipment, manufacturers' list prices were used. Even though some dealers absorb freight, a freight allowance was added to each list price on the basis of a 500-mile shipment for machines manufactured within the South and a 1,000-mile shipment for those produced in other regions. Rates supplied by a railroad traffic agent per 100 pounds for less-than-carload lots were $2.53 for 500 miles and $3.78 for 1,000 miles. No sales taxes were added. This is consistent with the practice in states like North Carolina, which do not tax manufacturers' purchases, but is inconsistent with others such as Georgia, which tax all sales. Installation costs were added, where appropriate, to get total investments.

Total daily cost for a piece of equipment is the sum of interest on average investment, amortization of investment, ad valorem taxes, fire and extended coverage insurance, and maintenance cost. An interest rate of 6 percent per annum was charged on the average investment, which was determined from the formula $I(N+1)/2N$, where I is total investment and N

is the estimated number of years the machine will be owned. No allowance was made for trade-ins or salvage; the total investment was depreciated by the straight-line method over the life of the machine. In calculating property taxes, assessed value was taken as 50 percent of full value less depreciation (i.e., average assessed value was one-half average investment), and the tax rate applied was $1.50 per $100 of assessed value. The premium for fire insurance and extended coverage was calculated on the basis of insured value equaling 80 percent of original value and a rate of $3.15 per $1,000 of insured value. These annual costs were reduced to a daily basis by assuming 225 eight-hour working days per year. Most of the assumptions made in calculating investment and cost tend to make the total daily cost estimates conservative (high).

Daily output is expressed in bark-free cords of slabs and edgings (79 cubic feet of solid wood). One and one-half rough cords are required to yield one bark-free cord of slabs and edgings. Thus, an output of 0.9 rough cords of slabs and edgings per thousand board-feet of lumber outturn at small sawmills will yield 0.6 bark-free cords.

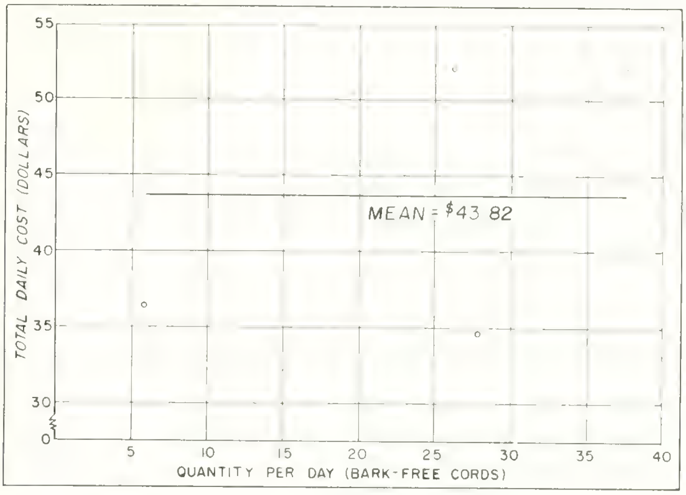
The machines used to convert rough slabs into clean chips consist of barkers, chippers, and conveyors to move material to and from them. The machine rates or operating capacities employed are approximately 75 percent of theoretical capacity. The total daily cost of operating machines does not include power, since in the case of electricity this cost varies with total installed horsepower as well as with individual machine requirements. Horsepower requirements by output for each type of machine are discussed in a later section and power costs by horsepower are presented separately.

Labor is included in the total daily cost of barkers. Other equipment costs do not include labor. The cost of additional labor for these other machines is also presented separately.

MACHINE COSTS--LOG BARKERS

Daily log-barking costs were calculated for three mechanical log barkers and one mechanical pulpwood barker which the manufacturer claimed could be modified to debark logs. Price and cost data for these barkers were obtained from published data in one case, from the manufacturer for another, and from users for the remaining two. All barkers were depreciated over 5 years, which was the period favored by users. Maintenance costs were those expected by manufacturers or experienced by users. The cost of added labor at sawmills where barkers had been installed is included in the daily cost. For three of the barkers, an additional semiskilled ($1.25-per-hour) and an unskilled ($1-per-hour) worker would be required. For the fourth barker, which feeds automatically, only one semiskilled man would be needed. The total daily costs of these four barkers plotted over residue output showed no discernible trend. Therefore, daily cost at any level of output was taken to be the average daily cost ($43.82) of these four barkers.

Daily cost of owning and operating log barkers (including labor but excluding power), by capacity



	Capacity (bark-free cords per day)			
	5.8	26.2	27.8	37.4
	Dollars			
Investment				
List price	3,000	24,000	17,000	15,000
Plus freight	90	305	85	305
Plus installation cost	500	3,000	3,000	3,000
Less knives or chains	40	40	(1/)	40
Total investment	3,550	27,265	20,085	18,265
Time charges				
Machine				
Interest at 6 percent on average investment	.57	4.36	3.21	2.92
Amortization of investment in 5 years	3.16	24.24	17.85	16.24
Ad valorem taxes	.07	.54	.40	.36
Fire and extended coverage insurance	.04	.31	.22	.20
Maintenance	13.20	3.29	1.78	13.20
Total machine cost	17.04	32.74	23.46	32.92
Labor				
Wages	18.00	18.00	10.00	18.00
Payments for Social Security, state unemployment compensation, and workmen's insurance	1.44	1.44	.80	1.44
Total labor cost	19.44	19.44	10.80	19.44
Total cost (for one 8-hour day)	36.48	52.18	34.26	52.36

1/ No chains or knives.

There are two general types of slab barkers--mechanical and hydraulic. Comparisons of operating costs (including power) indicate that mechanical barkers have the lowest average costs at outputs of less than 55 bark-free cords per day, while hydraulic barkers are more economical at larger outputs. This breakeven point was calculated from the data and assumptions presented here, and is not intended to apply to specific machines.

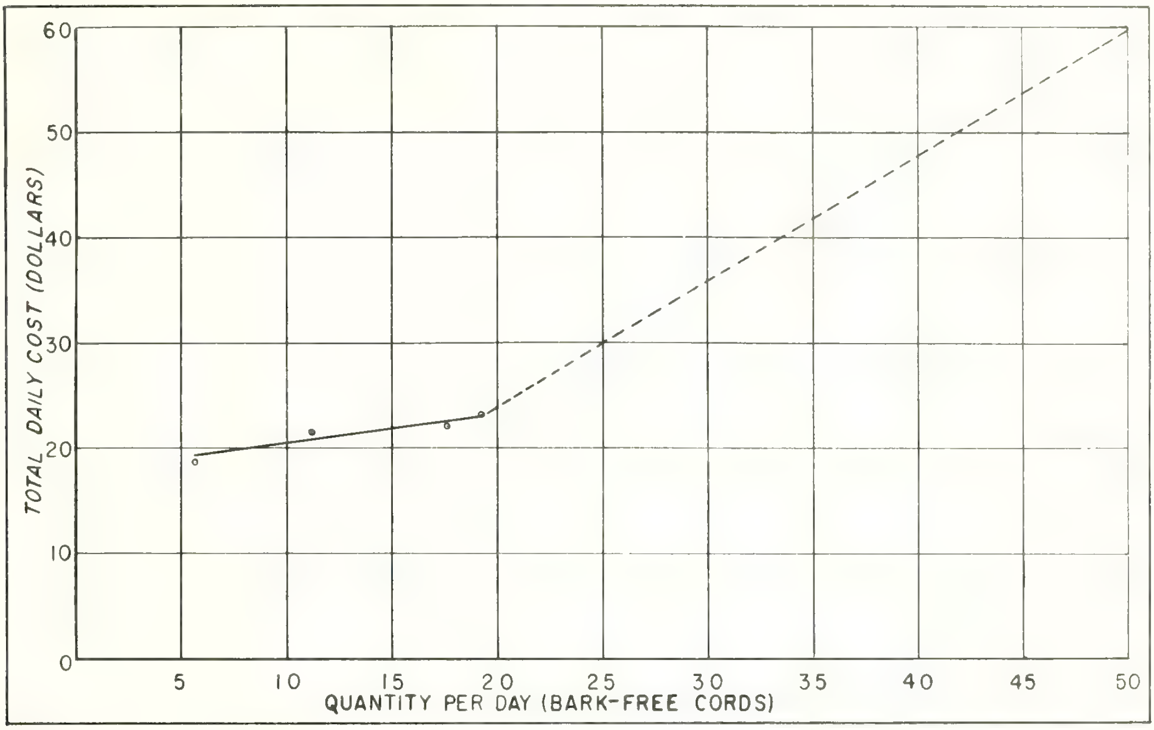
Total daily costs were calculated for four mechanical slab barkers which removed bark by chain flail, hammer, rosser head, or disc-mounted knife. Price and cost data came from published material and interviews with manufacturers and users. The life of slab barkers was taken to be 5 years, or the same as for log barkers. This is in accord with the opinion of some manufacturers and most users. Because mechanical slab barkers are still in an early state of development, the chance of obsolescence due to rapid changes in design and construction are high.

Maintenance costs were approximated from information supplied by manufacturers and users. Labor was included by adding in wages and other payments for one or two unskilled laborers as recommended by manufacturers or users. The total daily cost values when plotted over output fell very nearly in a straight line.

The trend of the fitted line could have been projected over larger outputs. If this were done, the mechanical barkers would show lower costs than the hydraulic barkers at all outputs considered. This was known to be unrealistic, since hydraulic barkers with daily capacities as low as 40 cords are marketed. Therefore, it was decided to assume arbitrarily that at outputs beyond 19 bark-free cords per day (the largest mechanical barker for which we had data) increased outputs would be obtained only by increasing the number of units. It was on this basis that the daily cost curve for mechanical barkers was projected.

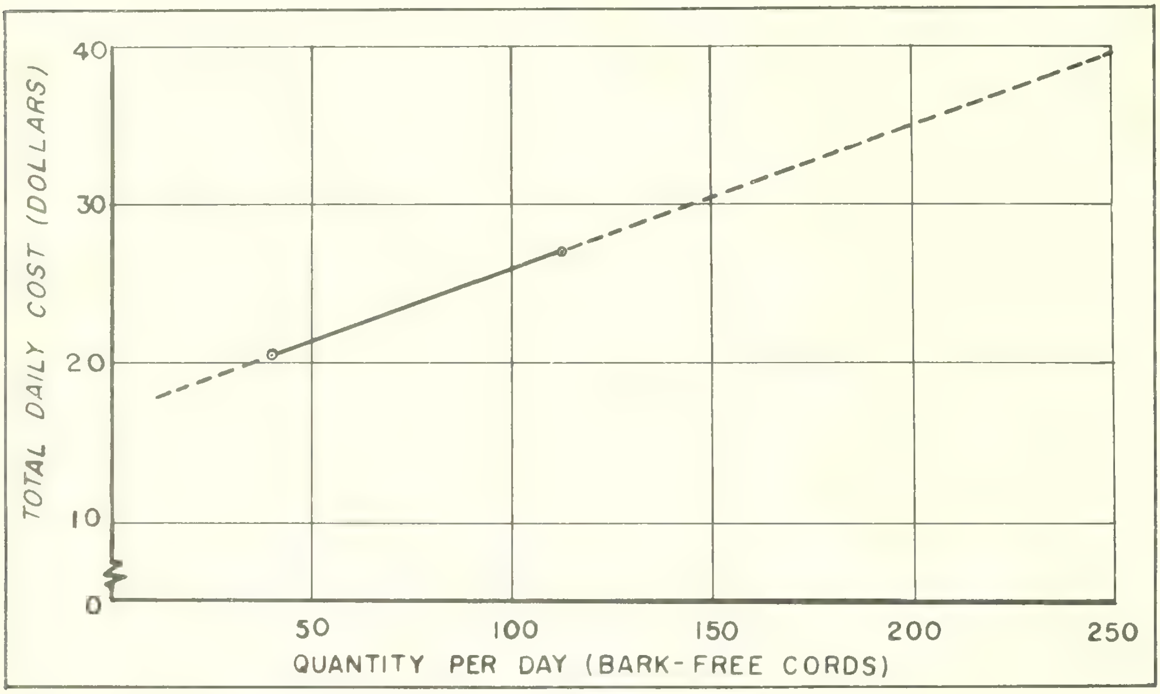
The curve for daily operating costs for hydraulic slab barkers was based on costs for two models. The data for one were obtained from an interview with the manufacturer, and for the other from published figures. Hydraulic barkers were depreciated over 10 years because these machines are subject to less vibration and have fewer wearing parts than mechanical models. Maintenance costs were based on manufacturer's estimates, because none of these machines had been operated a sufficiently long time to provide experience to date. The wages and labor payments for one unskilled operator to feed slabs and edgings were included in the cost of each machine.

Daily cost of owning and operating mechanical slab barkers (including labor but excluding power), by capacity



	Capacity (bark-free cords per day)			
	5.6	11.2	17.6	19.2
	Dollars			
Investment				
List price	1,000	9,200	8,250	3,500
Freight	25	50	100	50
Installation cost	100	100	100	100
Total investment	1,125	9,350	8,450	3,650
Time charges				
Machine				
Interest at 6 percent on average investment	.18	1.50	1.35	.58
Amortization of investment in 5 years	1.00	8.31	7.51	3.24
Ad valorem taxes	.02	.16	.14	.06
Fire and extended coverage insurance	.01	.10	.09	.04
Maintenance	.25	2.80	4.40	2.00
Total machine cost	1.46	12.87	13.49	5.92
Labor				
Wages	16.00	8.00	8.00	16.00
Payment for Social Security, state unemployment compensation, and workmen's insurance	1.28	.64	.64	1.28
Total labor cost	17.28	8.64	8.64	17.28
Total cost (for one 8-hour day)	18.74	21.51	22.13	23.20

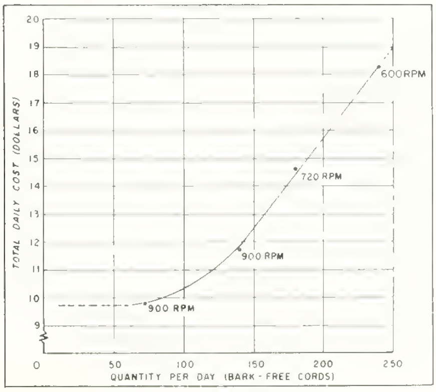
Daily cost of owning and operating hydraulic slab barkers (including labor excluding power), by capacity



	Capacity (bark-free cords per day)	
	40.0	112.0
	Dollars	
Investment		
List price	15,512	20,000
Freight	150	200
Installation cost	300	400
Total investment	15,962	20,600
Time charges		
Machine		
Interest at 6 percent on average investment	2.34	3.03
Amortization of investment in 10 years	7.09	9.15
Ad valorem taxes	.29	.37
Fire and extended coverage insurance	.18	.23
Maintenance	2.00	5.60
Total machine cost	11.90	18.38
Labor		
Wages	8.00	8.00
Payment for Social Security, state unemployment compensation and workmen's insurance	.64	.64
Total labor cost	8.64	8.64
Total cost (for one 8-hour day)	20.54	27.02

The total daily cost of owning and operating chippers was calculated for 6-knife machines with disc diameters of 36, 48, 60, and 74 inches. They are of a design which provides a positive feed without feed works. Their prices were therefore somewhat lower than machines requiring this additional mechanism. Chipper investment was amortized in 10 years, the period over which most users planned to depreciate them. Maintenance costs were based on the average practices of users. Most users change and sharpen knives daily and replace them every 4 months. They turn the anvil every 3 weeks, and since it has 4 sides, replace it every 12 weeks. Chipper costs were plotted over capacity outputs, based on $12\frac{1}{2}$ percent spout loading. In projecting chipper costs over outputs less than the capacity of the smallest chipper, it was assumed that costs would not be significantly reduced at these outputs.

Daily cost of owning and operating 6-knife chippers (excluding cost of labor and power), by capacity

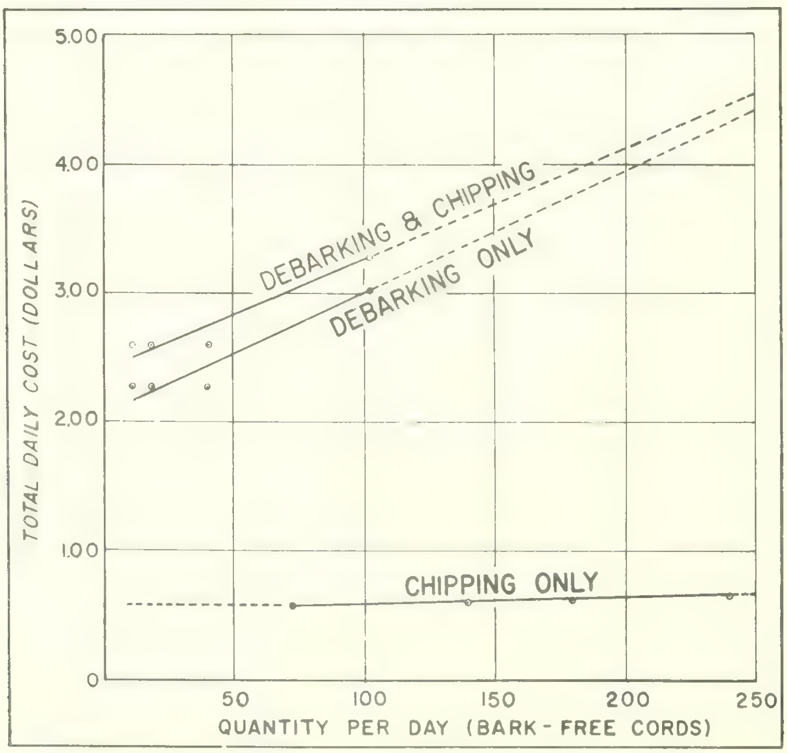


	Capacity (bark-free cords per day)			
	72	140	180	240
	Dollars			
Investment				
List price	5,260	8,015	12,180	17,480
Plus freight	80	150	255	410
Less knives and belts	200	225	245	270
Total investment	5,140	7,940	12,190	17,620
Time charges				
Interest at 6 percent on average investment	.75	1.16	1.79	2.58
Amortization of investment in 10 years	2.28	3.53	5.42	7.83
Ad valorem taxes	.10	.15	.23	.33
Fire and extended coverage insurance	.06	.09	.14	.20
Maintenance	6.55	6.80	7.05	7.35
Total cost (for one 8-hour day)	9.74	11.73	14.63	18.29

Daily costs were calculated for three conveyor systems at pulpmills or field locations. One system is for an installation processing only clean slabs into chips, another for one only debarking rough slabs, and the third is for a complete installation converting rough slabs to clean chips. A chipper installation would require merely a belt conveyor about 25 feet long conveying slabs to the chipper, and a blow pipe about 25 feet long leading to the loading point. A barker installation would require a 25-foot belt conveyor for rough slabs leading to the barker, a second 25-foot belt conveyor to move clean slabs to the loading point, and a 100-foot drag chain to carry bark from the barker to the burner. A complete installation would require a belt conveyor for rough slabs to the barker, a drag chain for bark to the burner, a belt for clean slabs between barker and chipper, and a blow pipe for chips from the chipper to the loading point.

Conveyor prices and assembly costs were obtained from the engineer for a wholesale firm selling both fabricated conveyors and parts and pieces. Conveyor systems were depreciated over 5 years, except in the case of chipper installations, where a 10-year period was used to coincide with the period used for chippers. Balanced curves were fitted to the plotted points and the trends projected. In the case of the system for chipper installations, cost was projected horizontally over lower outputs the same as for chippers.

Daily cost of owning and operating conveyor systems (excluding power) for three kinds of installations, by capacity



CHIPPER INSTALLATION

	Capacity (bark-free cords per day)							
	11.2	17.6	40	72	112	140	180	240
	Dollars							
Investment								
List price	--	--	--	763	--	813	838	888
Freight	--	--	--	25	--	25	25	25
Installation cost	--	--	--	150	--	155	160	165
Total investment	--	--	--	938	--	993	1,023	1,078
Time charges								
Interest at 6 percent on average investment	--	--	--	.14	--	.15	.15	.16
Amortization of investment in 10 years	--	--	--	.42	--	.44	.45	.48
Ad valorem taxes	--	--	--	.02	--	.02	.02	.02
Fire and extended coverage insurance	--	--	--	.01	--	.01	.01	.01
Maintenance	--	--	--	(1/)	--	(1/)	(1/)	(1/)
Total cost (for one 8-hour day)	--	--	--	.59	--	.62	.63	.67

BARKER INSTALLATION

	11.2	17.6	40	72	112	140	180	240
Investment								
List price	1,751	1,751	1,751	--	2,305	--	--	--
Freight	60	60	60	--	100	--	--	--
Installation cost	290	290	290	--	390	--	--	--
Total investment	2,101	2,101	2,101	--	2,795	--	--	--
Time charges								
Interest at 6 percent on average investment	.34	.34	.34	--	.45	--	--	--
Amortization of investment in 5 years	1.87	1.87	1.87	--	2.48	--	--	--
Ad valorem taxes	.04	.04	.04	--	.06	--	--	--
Fire and extended coverage insurance	.02	.02	.02	--	.03	--	--	--
Maintenance	(1/)	(1/)	(1/)	--	(1/)	--	--	--
Total cost (for one 8-hour day)	2.27	2.27	2.27	--	3.02	--	--	--

COMBINED BARKER AND CHIPPER INSTALLATION

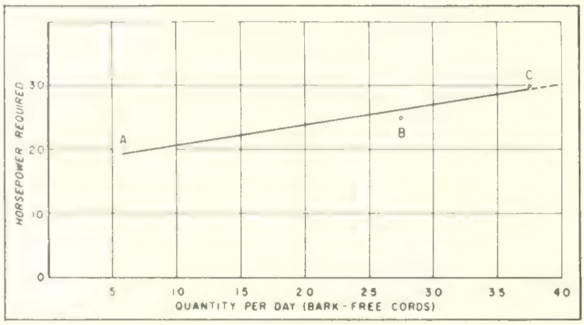
	11.2	17.6	40	72	112	140	180	240
Investment								
List price	1,986	1,986	1,986	--	2,540	--	--	--
Freight	65	65	65	--	105	--	--	--
Installation cost	340	340	340	--	395	--	--	--
Total investment	2,391	2,391	2,391	--	3,040	--	--	--
Time charges								
Interest at 6 percent on average investment	.38	.38	.38	--	.49	--	--	--
Amortization of investment in 5 years	2.13	2.13	2.13	--	2.70	--	--	--
Ad valorem taxes	.05	.05	.05	--	.06	--	--	--
Fire and extended coverage insurance	.03	.03	.03	--	.03	--	--	--
Maintenance	(1/)	(1/)	(1/)	--	(1/)	--	--	--
Total cost (for one 8-hour day)	2.59	2.59	2.59	--	3.28	--	--	--

1/ Assumed no maintenance cost.

To relate power to machines, it was necessary to know for each type of machine the relationship between residue output and horsepower requirements. The horsepower requirements given by manufacturers and users of individual pieces of machinery were plotted over operating outputs. Straight line balanced curves were then fitted graphically to each set of plotted points. Extrapolations were necessary for mechanical log barkers and hydraulic slab barkers. The horsepower requirements for mechanical slab barkers were projected on the assumption that additional units would be needed for volumes greater than 19 cords. For chippers the same horsepower was shown for all outputs up to 72 cords per day, since the same machine could be used at all of these outputs. Conveyor horsepower requirements were calculated separately for barker installations, chipper installations, and complete debarking and chipping installations.

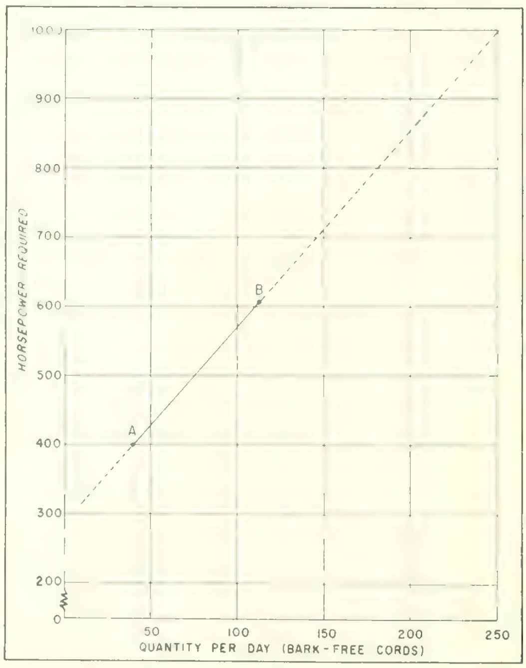
Average horsepower required for mechanical log barkers, by capacity

Mechanical log barker	Daily output	Power requirements
	Bark-free cords	Horsepower
A	5.8	20.0
B	27.5	25.0
C	37.5	60.0

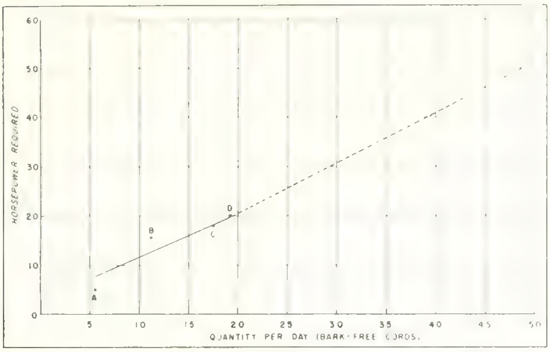


Average horsepower required for hydraulic slab barkers, by capacity

Hydraulic slab barker	Daily output	Power requirements
	Bark-free cords	Horsepower
A	40	400.0
B	112	605.0

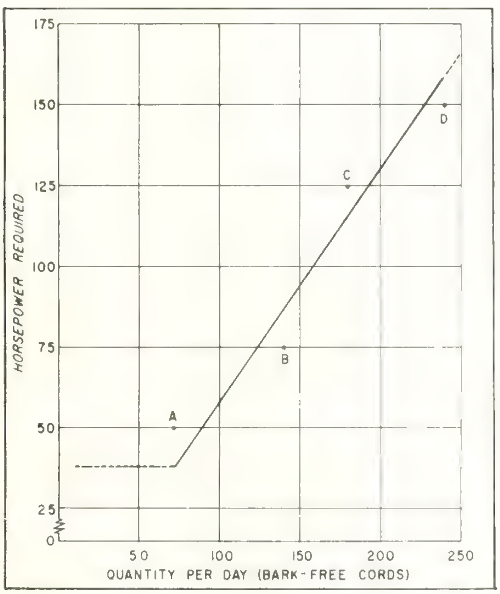


Average horsepower required for mechanical slab barkers, by capacity



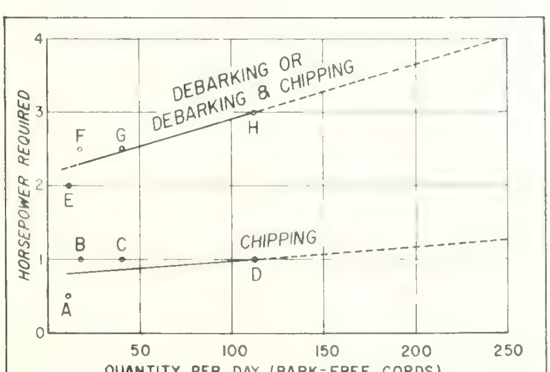
Mechanical slab barker	Daily output	Power requirements
	Bark-free cords	Horsepower
A	5.6	5.0
B	11.2	15.5
C	17.6	18.0
D	19.2	20.0

Average horsepower required for chippers, by capacity



Chipper	Daily output	Power requirements
	Bark-free cords	Horsepower
A	72	50.0
B	140	75.0
C	180	125.0
D	240	150.0

Average horsepower required for three conveyor systems, by capacity



Conveyor system	Daily output	Power requirements
	Bark-free cords	Horsepower
Chipping		
A	11.2	0.5
B	17.6	1.0
C	40.0	1.0
D	112.0	1.0
Debarking or debarking and chipping		
E	11.2	2.0
F	17.6	2.5
G	40.0	2.5
H	112.0	3.0

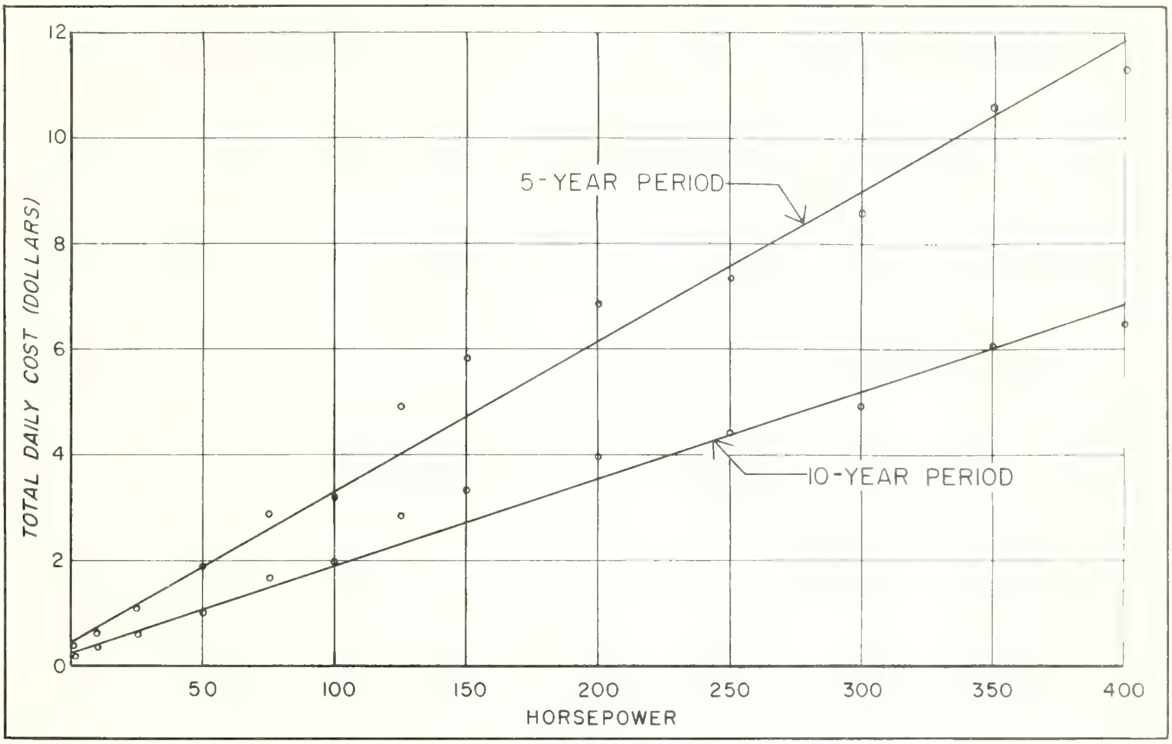
The cost of electric power consists of the expense of the motor and the charge for current to drive it. Electric motor costs were calculated on the basis of both 5- and 10-year depreciation periods. This was done on the perhaps oversimplified assumption that the motor would be discarded with the equipment it powers. Motor prices were obtained from a manufacturer. Prices were for 3-phase, squirrel cage, induction motors with drip-proof enclosures. The motors of 200 horsepower or less operate at approximately 1,800 rpm on 220-, 440-, or 550-volt current, while the larger motors operate at 3,600 rpm on 2,300-volt current. The price of a starter was added to the price of each motor.

In calculating daily cost, no charge for maintenance was included. A motor used only 5 years would be unlikely to have any maintenance cost. Although a motor used 10 years probably would require some maintenance, the cost would be small and difficult to estimate.

Electricity for industrial use is generally sold on two schedules, one for small and one for large consumers. Calculations based on the rates used here show that the small general service schedule results in the lowest cost to customers whose motors total less than 65 horsepower, while the large general service schedule would be advantageous for those using 65 horsepower or more. These are the rates charged by one utility company, but the rates of other companies in the Southeast should be similar.

The rate schedules used in calculating the bill for these two levels of service differ in form. The schedule of rates for small general service is such that it enables the customer to buy additional electricity at lower rates. The large general service customer pays a minimum or demand charge based upon the size of his installation. To this is added a charge for the amount of electricity he uses, which is figured at lower rates than those for the small general service user. Finally, if he is a very large consumer, there is a fuel adjustment which varies the charges with changes in the price of coal.

Daily cost of owning and maintaining electric motors for 5- and 10-year periods (excluding cost of current), by horsepower



5-YEAR PERIOD

	Horsepower												
	1	10	25	50	75	100	125	150	200	250	300	350	400
	Dollars												
Investment													
List price of motor	117	352	653	1,118	1,674	2,145	2,581	3,421	4,370	4,560	5,248	5,858	6,528
Plus list price of starter	195	195	318	446	947	947	1,900	1,900	1,900	2,150	2,664	3,850	3,850
Plus freight	2	7	14	25	38	49	54	59	68	77	86	96	106
Total investment	314	554	985	1,589	2,659	3,141	4,535	5,380	6,338	6,787	7,998	9,804	10,484
Time charges													
Interest at 6 percent on average investment	.05	.09	.16	.25	.43	.50	.73	.86	1.01	1.09	1.28	1.57	1.68
Amortization of investment in 5 years	.28	.49	.88	1.41	2.36	2.79	4.03	4.78	5.63	6.03	7.11	8.72	9.32
Ad valorem taxes	.01	.01	.02	.03	.05	.06	.09	.11	.13	.14	.16	.20	.21
Fire and extended coverage insurance	(1/)	.01	.01	.02	.03	.04	.05	.06	.07	.08	.09	.11	.12
Maintenance	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Total cost (for one 8-hour day)	.34	.60	1.07	1.71	2.87	3.39	4.90	5.81	6.84	7.34	8.64	10.60	11.33

10-YEAR PERIOD

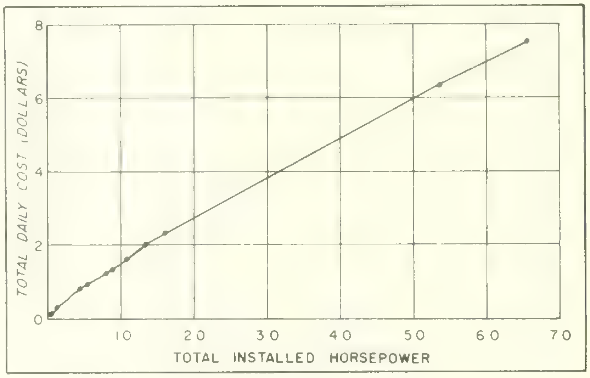
	1	10	25	50	75	100	125	150	200	250	300	350	400
Time charges													
Interest at 6 percent on average investment	.05	.08	.14	.23	.39	.46	.67	.79	.93	1.00	1.17	1.44	1.54
Amortization of investment in 10 years	.14	.25	.44	.71	1.18	1.40	2.02	2.39	2.82	3.02	3.55	4.36	4.66
Ad valorem taxes	.01	.01	.02	.03	.05	.06	.08	.10	.12	.12	.15	.18	.19
Insurance	(1/)	.01	.01	.02	.03	.04	.05	.06	.07	.08	.09	.11	.12
Maintenance	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Total cost (for one 8-hour day)	.20	.35	.61	.99	1.65	1.96	2.82	3.34	3.94	4.42	4.96	6.09	6.51

1/ Less than ½ cent.

Daily cost of electric current at small general service rate, by total installed horsepower

Horsepower	Kilowatts 1/	Kilowatt hours per month	Total cost 2/	
			Month	Day
Hp.	Kw.	Kwh	- - - Dollars	- - - -
0.5	[illegible] 4	55.5	2 05	11
1.3	1 [illegible]	150.0	5.55	30
2.0	1.5	225.0	7.80	42
4.5	3.3	500.0	16.05	86
5.4	4 0	600.0	17.45	93
8.0	6.0	900.0	[illegible]	1 24
8.9	6 7	1,000.0	25.72	1.37
10.7	8 0	1,200.0	30.65	1 63
13.4	10 [illegible]	1,500.0	38.05	2 03
16.1	12 [illegible]	[illegible]	43.45	2 32
53.6	40 0	6,000.0	119.05	6.35
67.0	50 [illegible]	7,500.0	144.25	7 69
99.2	74 0	11,100.0	202.57	10 80

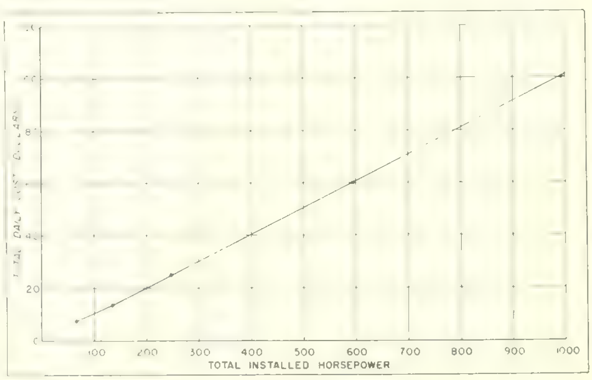
1/ 1 hp. = 0.746 kw.
2/ Costs were calculated on the basis of the following monthly rate schedule and adjustments:
$0.037 per kwh for the first 150 kwh
.030 per kwh for the next 350 kwh
.014 per kwh for the next 500 kwh
.010 per kwh for the next 3000 kwh
.007 per kwh for all additional kwh
When, between 150 and 500 kwh, demand exceeds 5 kw, 100 kwh are added for each of the first 5 kw of such excess and 60 kwh for each additional kw of this excess.



Daily cost of electric current at large general service rate, by total installed horsepower

Horsepower	Kilowatts 1/	Kilowatt hours per month	Total cost 2/	
			Month	Day
Hp.	Kw.	Kwh.	- - - Dollars	- - -
53 6	40.0	6,000	132 00	7.04
67.0	50.0	7,500	142 50	7.60
68.4	51.0	7,650	144 75	7.72
73.7	55.0	8,250	153 75	8.20
99 2	74.0	11,100	196 50	10.48
134.0	100.0	15,000	255.00	13.60
248.0	185.0	27,750	471 11	25.12
595.2	444.0	66,600	1,129 62	60.24
992.0	740.0	111,000	1,882 20	100.38

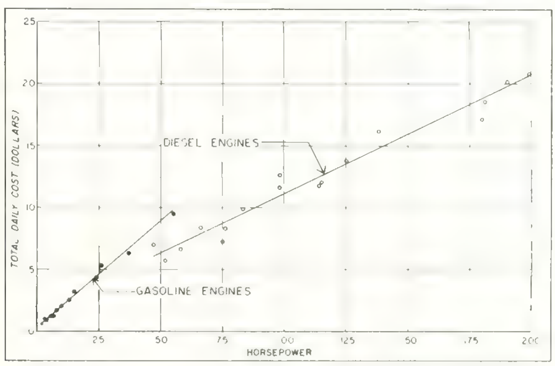
1/ 1 hp. = 0.746 kw.
2/ Costs were calculated on the basis of the following monthly charges and adjustments:
Demand charge:
$90 per month for first 50 kw.
$1.20 per month for each kw over 50 kw.
Energy charge:
$0.0070 per kwh for first 250,000 kwh per month
.0060 per kwh for 250,000 to 500,000 kwh per month
.0055 per kwh for all kwh over 500,000 kwh per month
Fuel adjustment:
Price of coal at $9 per ton increased net monthly bill by $0.00195 per kwh for each kwh in excess of 15,000 kwh per month



Although daily cost curves for diesel and gasoline engines do not meet within the range of the data, it is obvious that gasoline engines are cheaper to operate at low horsepowers, and diesel engines at higher horsepowers. The break-even point between them is below 50 horsepower.

Price and cost data were obtained for 3 makes and 15 models of gasoline engines, and 3 makes and 17 models of diesel engines. This information was supplied by dealers. Engines were depreciated in 5 years, the period preferred by most users, although dealers suggested a longer interval. Maintenance costs, and oil and fuel consumption were taken from manufacturers' records or calculated on the basis of recommended practices. Gasoline and oil prices are those actually paid by users.

Daily cost of owning and operating gasoline and diesel engines, by horsepower



Gasoline engines

	Horsepower rating (continuous)														
	2	3	4	[illegible]	7	[illegible]	8	[illegible]	[illegible]	13	[illegible]	24	26	[illegible]	[illegible]
	Dollars														
Investment															
List price	68	83	[illegible]	[illegible]	[illegible]	[illegible]	188	[illegible]	[illegible]	247	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Freight	5	[illegible]	[illegible]	5	[illegible]	5	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	[illegible]	[illegible]
Total investment	73	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,078
Time charges															
Interest at 6 percent on average investment	01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Amortization of investment in 5 years	06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ad valorem taxes	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fire and extended coverage insurance	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Maintenance	15	15	[illegible]	07	07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lubricating oil consumption 2/	13	26	07	07	07	[illegible]	16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fuel consumption 3/	28	57	[illegible]	[illegible]	[illegible]	1.34	1.32	1.60	1.54	[illegible]	2.68	[illegible]	[illegible]	[illegible]	[illegible]
Total cost (for one 8-hour day)	63	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1/ Less than ½ cent
2/ Twenty-five cents per quart
3/ Nineteen cents per gallon

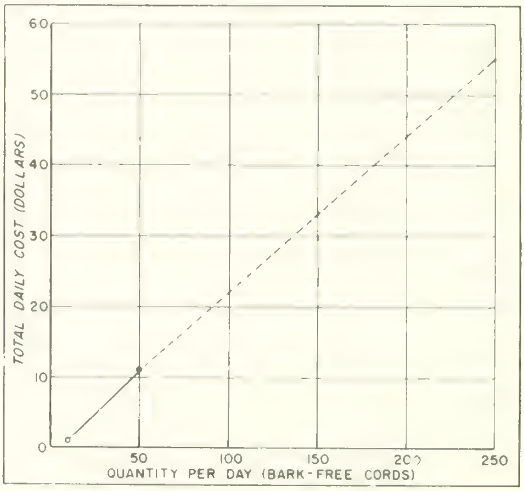
Diesel engines

	Horsepower rating (continuous)																
	47	52	[illegible]	[illegible]	75	[illegible]	83	88	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Dollars																
Investment																	
List price	2,578	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Freight and taxes	130	70	55	120	[illegible]	[illegible]	[illegible]	[illegible]	200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total investment	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Time charges																	
Interest at 6 percent on average investment	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Amortization of investment in 5 years	2.41	1.86	2.23	[illegible]	[illegible]	2.74	[illegible]	3.83	[illegible]	3.35	3.57	4.17	5.12	4.53	6.54	[illegible]	[illegible]
Ad valorem taxes	.05	04	.05	[illegible]	05	06	[illegible]	.09	.11	[illegible]	[illegible]	[illegible]	.12	[illegible]	[illegible]	[illegible]	[illegible]
Fire and extended coverage insurance	.03	.02	.03	04	.03	[illegible]	04	.05	[illegible]	.04	04	.05	06	06	[illegible]	07	08
Maintenance	.51	.40	.22	59	[illegible]	.54	.22	83	[illegible]	.22	.68	[illegible]	[illegible]	22	1.06	[illegible]	[illegible]
Lubricating oil consumption 1/	[illegible]	.07	[illegible]	26	09	.13	.24	.39	41	.27	.15	22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fuel consumption 2/	3.36	3.01	3.58	3.92	[illegible]	4.35	5.49	5.71	5.71	7.17	6.90	7.71	8.29	10.98	8.96	[illegible]	[illegible]
Total cost (for one 8-hour day)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1/ One dollar per gallon
2/ Fourteen cents per gallon

Slab lifting equipment costs were calculated for 10-cord-per-day and 50-cord-per-day yards. For the smaller yard, cost was based on the use of a derrick with a hand-operated hoist to unload slabs from trucks. Such a derrick would need a 30-foot mast, a 25-foot boom, and a lifting capacity of 8,000 pounds to make it possible to remove $1\frac{1}{2}$ cords (half a truckload) at a time. The volume that could be handled in this way would be limited by the circumference covered by the boom. Prices for parts and pieces were obtained from published sources. To these were added the estimated cost of assembly. Investment was amortized in 5 years. Maintenance costs were estimated. Slab handling costs at a 50-cord yard were for a lift truck which could move slabs in and out of storage. Price was obtained from a published source for a simple type of lift truck, consisting merely of a hoisting mechanism mounted on a truck chassis. The truck was depreciated in 5 years. Maintenance and fuel costs were derived from published figures. A curve was drawn connecting the point for the 10-cord yard with the one for the 50-cord yard. Projection of this curve over larger outputs was made on the assumption that additional lift trucks would be purchased as yard size increased.

Daily cost of owning and operating slab lifting equipment, by capacity

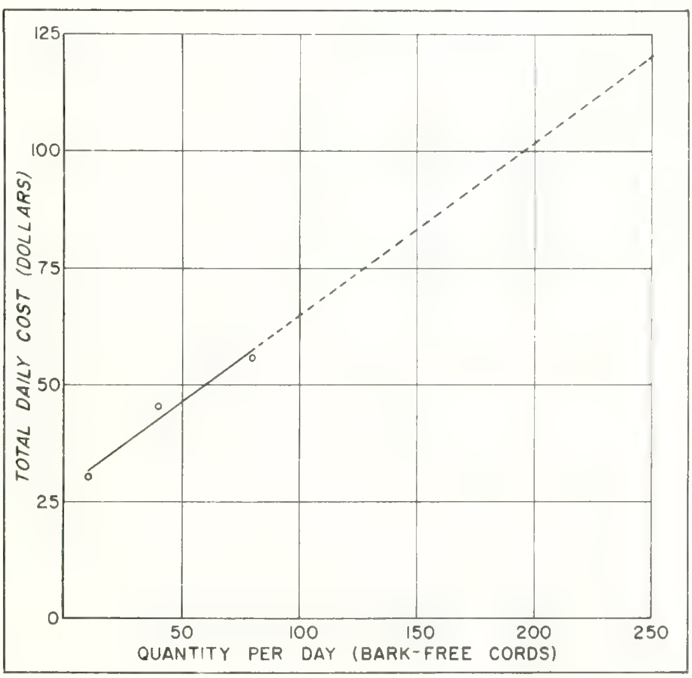


	Capacity (bark-free cords per day)	
	10	50
	Dollars	
Investment		
List price	330	5,285
Freight	10	450
Installation cost	200	00
Total investment	540	5,735
Time charges		
Interest at 6 percent on average investment	0.09	0.92
Amortization of investment in 5 years	.48	5.10
Ad valorem taxes	.01	.11
Fire and extended coverage insurance	.01	.06
Maintenance	.54	3.95
Fuel 1/	.00	.84
Total cost (for one 8-hour day)	1.13	10.98

1/ Nineteen cents per gallon.

The cost of additional labor for chipper and complete barker and chipper installations was estimated for three sizes of yards. A 10-cord yard would need 2 additional men and a foreman; a 40-cord yard 2 additional men, a lift-truck operator, and a foreman; and an 80-cord yard 3 additional men, a lift-truck operator, and a foreman. Labor costs are composed of wages and other payments. A minimum wage of $1 an hour was used for unskilled labor; at the other end of the scale, foremen's wages varied with size of yard. The other payments include Social Security, state unemployment compensation, and workman's insurance, which together amount to about 8 percent of wages. The plotted points fall nearly in a straight line. The trend of the line fitted to these points was extended over larger outputs.

Daily cost of additional labor for chipper installation or barker-chipper installation, by capacity



	Capacity (bark-free cords per day)		
	10	40	80
	- - - - - - - - - - - Dollars - - - - - - - -		
Time charges			
Wages	28.00	42.00	52.00
Payments for Social Security, state unemployment compensation, and workmen's insurance	2.24	3.36	4.16
Total cost (for one 8-hour day)	30.24	45.36	56.16

Station Paper No. 85

November 1957

Heavy Losses in Air Seasoning Georgia Pine and how to reduce them

by

Rufus H Page and Roy M. Carter

SOUTHEASTERN FOREST
EXPERIMENT STATION
Asheville, North Carolina

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Director

U. S. DEPARTMENT OF AGRICULTURE FOREST SERVICE

Grateful acknowledgment is extended to the members of the Georgia Forestry Commission who assisted in collecting the data contained in this report, and to those concentration yard owners and operators who made their facilities available in order that this study might be completed.

Heavy Losses in Air Seasoning Georgia Pine and how to reduce them

by

Rufus H. Page and Roy M. Carter

More southern pine lumber is produced in Georgia than in any other state in the nation. In 1953, nearly 2 billion board-feet were cut, representing a wholesale value of more than 150 million dollars. In addition, the total value of the lumber industries' contribution to the economy of the state is increased several times by remanufacturing operations and marketing processes. Hence, handling and seasoning methods affecting the value of the lumber are vital matters.

Only a small percentage of this 2 billion feet of pine lumber is kiln-dried. Most of it is air seasoned. This study indicates that losses by seasoning-degrade from the green to the dry state range from \$5.21 per thousand board-feet for package piled lumber to as much as \$26.21 per thousand board-feet for flat piled lumber. This means that for every million feet of lumber air seasoned, the average Georgia yard may suffer a potential loss in income of from \$5,000 to \$26,000. The average loss suffered from all seasoning-degrade by four methods of stacking involved in this study was \$10.21 per thousand board-feet, or \$10,000 per million board-feet.

Even more serious than this monetary loss is the competitive market situation developing with regard to southern pine lumber. Because much of this lumber has been placed on the market at too high a moisture content, with excessive stain, and containing noticeable warp, other wood species, metals, and synthetics have made marked inroads into the southern pine market. Several large Georgia lumber companies and numerous small ones have been forced to close during the past year. Had the demand been consistently strong and had additional revenue been realized from better seasoning practices, these concerns might have been able to survive the steadily rising cost of labor and stumpage.

Southern pine lumber is still unsurpassed for construction. It can, however, be sold at a premium only if the quality of the finished product is maintained at a high level. To do this means that it must be properly seasoned. An estimated 80-percent reduction of dollar losses from air seasoning is possible with simple, well known remedial measures and usually without a large outlay of money for additional equipment.

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Studies of air seasoning lumber have been made on several occasions (1, 2, 3, 4, 5, 6, 7). There are, however, no published research data on the different methods of stacking used in Georgia, nor has any determination of value losses from these methods been made. This study of air seasoning lumber in Georgia was made to determine the principal causes of seasoning-degrade, the extent of losses from current seasoning practices, and how these losses can be prevented.

DETAILS OF THE STUDY

Twenty yards throughout the state were visited for general information and a detailed study was made of one or more typical lumber piles at 18 of these yards (fig. 1). Owners and operators assisted materially by supplying information and by furnishing labor to tear down the stacks involved. Various sizes and kinds of yards were selected in an effort to obtain a representative cross-section (table 1).

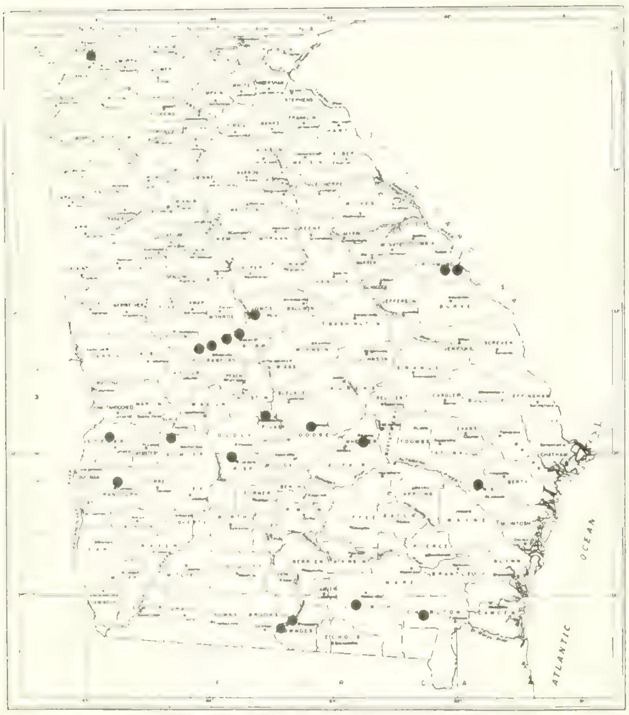

Figure 1.--Location of yards used in air seasoning study.

Thirteen factors which contributed to slow drying and degrade were used in rating the efficiency of these yards. They are summarized in table 2 and include yard surface, sanitation, drainage, aeration, foundation height and construction, stack covers, stack spacing, uniformity and alignment of stickers and bolsters, and the use of antistain chemicals. If no more than 3 of these conditions existed at a yard, it was rated "good," if from 4 to 6 "fair," and if more than 6 "poor." On this basis, 2 of the 20 yards involved were good, 12 fair, and 6 poor.

Detailed information was obtained from selected stacks of lumber to determine the extent of loss during air drying, and the specific factors causing this loss, as well as to gain a knowledge of the relative uniformity of drying brought about by various methods of stacking. This intensive study was made of 4/4 pine stacked to dry by four methods commonly used in Georgia. Definitions of stacking methods differ. For Georgia, however, the following pile descriptions are generally accepted by the wood-using industry:

Table 1.--Sizes and kinds of yards visited

Size class, and volume seasoned annually (Board-feet)	Wholesale only	Retail only	Wholesale and retail
	Number	Number	Number
Less than 3 million	2	1	0
3 to 6 million	1	1	2
6 to 9 million	3	0	2
9 million and over	7	0	1
Total	13	2	5

Table 2.--Factors contributing to slow drying and degrade at 20 air drying yards throughout Georgia

	Yards	Proportion
	Number	Percent
Weeds and debris in roadways and alleys and around piles	13	65
Yard sites poorly drained	3	15
Yards poorly aerated because of location or obstructions	2	10
Yard surfaces so rough as to constitute a hazard when operating lumber-handling equipment	3	15
Foundations too low for efficient air circulation	11	55
Foundations improperly constructed for efficient air circulation	7	35
No stack covers	15	75
Distance between stacks insufficient to permit rapid dryi ng	7	35
Stack construction so poor as to constitute a hazard or appreciably retard drying	2	10
Stickers unsized	6	30
Stickers unaligned or in wavy alignment	12	60
Foundation timbers and bolsters separating packages unaligned with stickers	6	30
Lumber not dipped in antistain solution before stacking	13	65

"Flat piled" most nearly conforms to the old method of hand stacking lumber by flat piling in 8-foot or wider piles, and piles so made are usually found on hand-operated yards. They may or may not be sloped, pitched, or covered, and are usually set on some kind of foundation so that the bottom courses are not in contact with the ground (fig. 2).

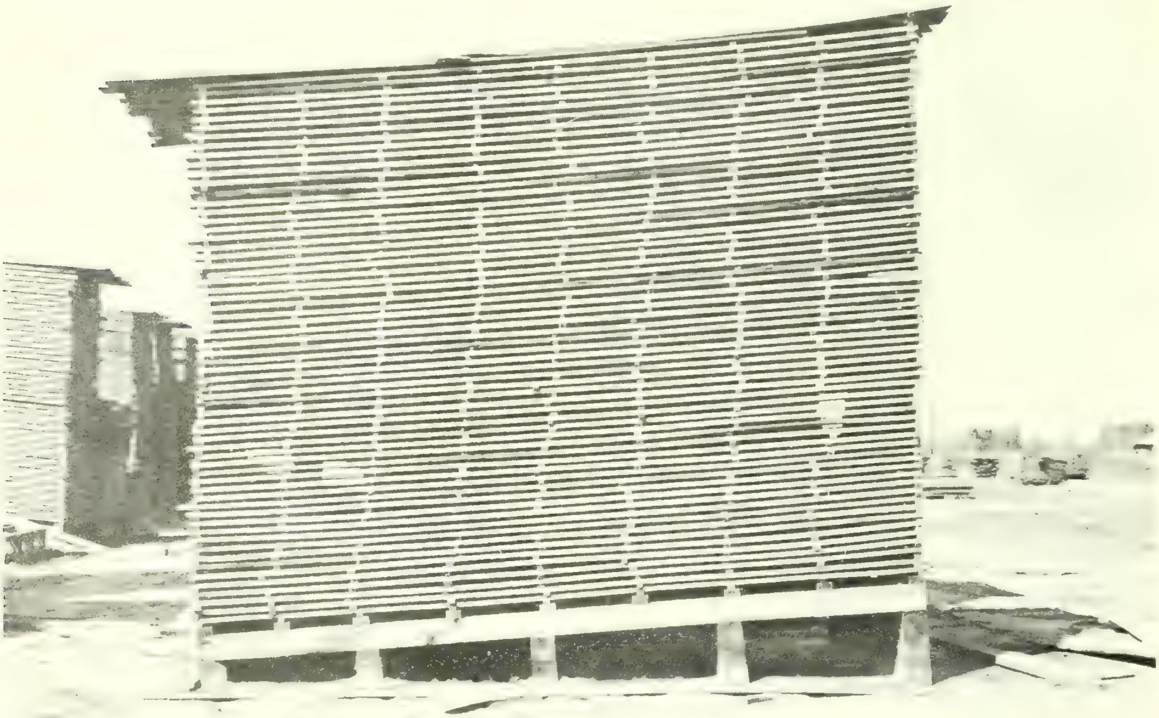

Figure 2.--A well constructed flat pile in south Georgia. Foundation timbers are made of treated material and the covers are sun- and rain-tight.

"Package piled" lumber is put up in unit packages for convenience of handling. These packages are usually 8 feet or less in width and are often made to conform to the dimensions of kiln trucks on those yards that kiln dry their better or special grades. A package pile normally consists of several unit packages separated by members called bolsters. These packages, transported by forklift trucks or similar devices, are a necessary part of yard mechanization (fig. 3).

"End piled" lumber refers to lumber stacked on end in a series of parallel courses. Lumber stacked in this manner might best be described as a flat pile stood on end. In many of the larger yards, lumber is end piled in stacks containing 25 M board-feet or more, since the length of the pile is limited only by available yard space (fig. 4).

"Crib piled" lumber is stacked by means of flat piling in a 3-sided pen or crib. A crib whose sides consist of a single tier of boards is single cribbed, of 2 boards is double cribbed, and of 3 boards is triple cribbed (fig. 5).

Figure 3.--Package piled pine in east Georgia. Both stickers and bolsters are well aligned to prevent excessive warping.

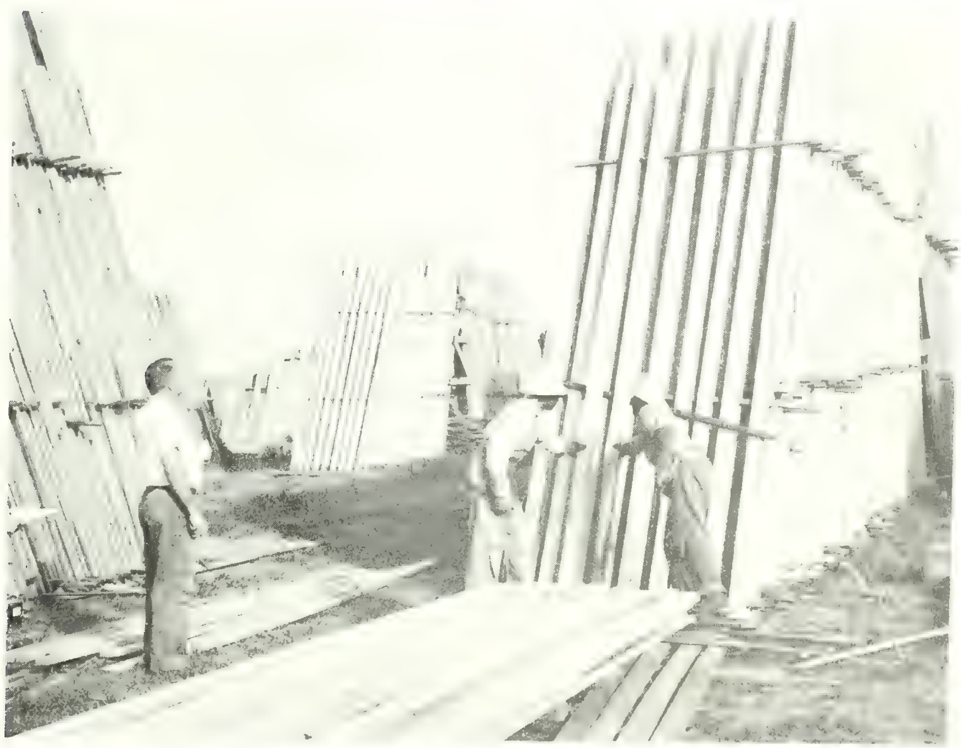

Figure 4.--In lumber dried by end piling, the board ends nearest the ground usually contain the most moisture and the top ends the least.

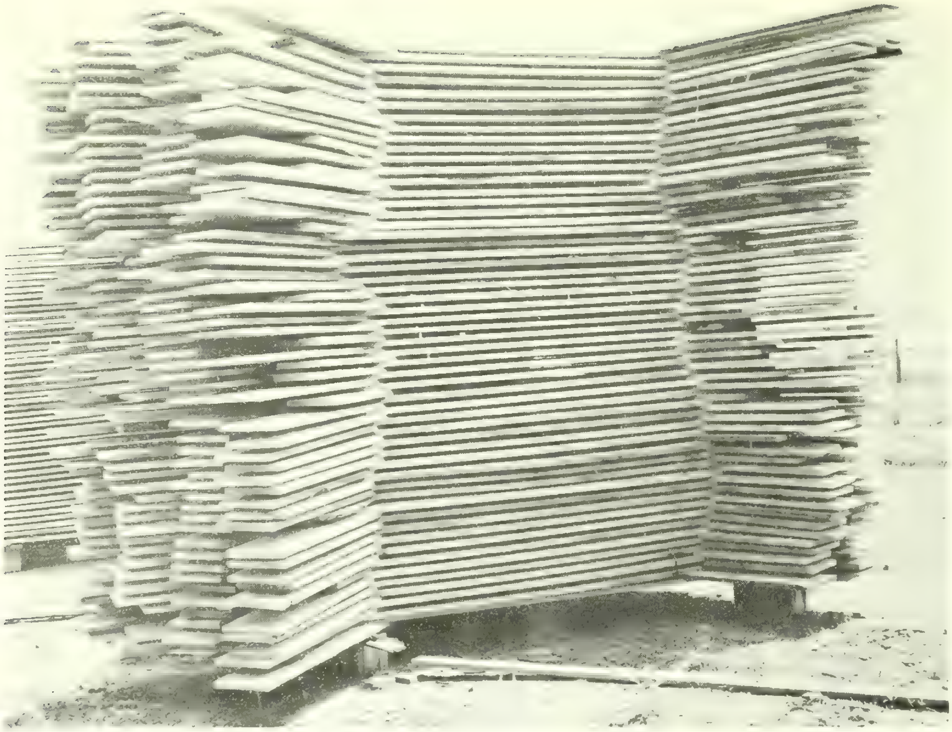

Figure 5.--Crib piled lumber dries rapidly except at the laps, but tends to warp because the boards are unsupported at the ends and centers.

The trend in air seasoning seems to be away from the flat pile, and, to a lesser extent, from the crib and end pile to the unit package pile. Perhaps the major factor responsible for this trend towards mechanization is the steadily rising cost of labor. One forklift truck will replace several yard hands and the whole operation of stacking, moving, and unstacking lumber is expedited by lumber-handling equipment. It seems reasonable to assume that in the next decade most of the concentration yards annually handling 5 million feet or more of lumber will be mechanized.

Lumber stacks selected for sampling had been drying from 19 to 172 days and all were considered air dry and ready to ship by the yard operators. Most of the lumber in individual piles was of uniform widths and lengths. Dimensions of lumber in different stacks ranged from 12 to 16 feet in length and from 4 to 12 inches in width.

The flat, package, and crib piles were sampled at different levels in the stack. All lumber contained in the three top courses was designated the top section, all lumber in the two bottom courses the bottom section, and two randomly selected boards from every other course between the top and bottom section the middle section. In end piles, 1 or 2 sample boards, depending on the size of the stack, were randomly selected from every course of the first 40 courses.

Each sample board was assigned two grades, one as if it contained no seasoning defects and one as it actually was. Southern Pine Inspection Bureau lumber grading rules for 1956 were followed in determining grades

and in describing defects. Moisture content determinations were made at a point 6 inches from one end and at the center of each sample board in the flat, package, and crib piles. An additional reading was taken from each board in the end piles, providing a top, middle, and bottom reading. A resistance-type moisture meter was used for this purpose. The grade, lumber tally, moisture content, and kind and amount of defects were recorded. Of a total of more than 40 M feet of lumber inspected, almost 8,500 feet was intensively studied (table 3).

Table 3.--A summary of volumes sampled by species and methods of piling

Method of piling	Stacks	Volume in samples	Volume in stacks	Ratio of sample volume to pile volume
	Number	Board-feet	Board-feet	Percent
Flat piled	4	2,252	8,998	25.0
Package piled	7	3,147	18,093	17.4
End piled	3	764	5,880	13.0
Crib piled	7	2,328	8,593	27.1
All methods	21	8,491	41,564	24.0

ANALYZING THE DATA

This report deals with averages, and not with individual board variations. A dollar value with and without air seasoning defects was assigned to each sample board on a basis of the board-foot content, grade, and current market value. The averages of these values were weighted according to volumes involved in the samples and sample stacks. The loss for each factor and by each method of piling was determined by subtracting the value of the boards before and after degrade. Seventy-eight dollars per thousand board-feet, the average wholesale price of No. 2 common air dried pine lumber in the Macon, Georgia, area at the time of the study, was used as a basis for these values. Values of other grades were then determined by using indices found in "Interim Log Grades for Southern Pine." [1]

The moisture content of the sample piles was analyzed to determine what influence different methods of stacking had on drying times and uniformity of drying of the lumber involved in this study.[2]

1/ An 18-page publication issued jointly in 1953 by the Southeastern Forest Experiment Station, the Southern Forest Experiment Station, Region 8, and the Forest Products Laboratory, Forest Service, U. S. Dept. Agr.

2/ Roy M. Carter and Rufus H. Page. Variation in moisture content of air seasoned southern pine lumber in Georgia. Publication pending in 1957 Forest Prod. Res. Soc. Proc.

In any analysis of loss by degrade and also of drying time and uniformity of drying, it is necessary to recognize that weather conditions play an important part in lumber drying and hence in the amount and kind of degrade, no matter how lumber is stacked. More rapid drying occurs when temperatures are high, relative humidities low, and when there is a rapid circulation of air. In the southeast, these factors are usually most favorable in the spring. As summer progresses, humidities as well as temperatures increase, and the winds subside somewhat. Conditions favorable to rapid drying, however, generally continue on into fall. Drying is slowed appreciably during cold, wet weather, and if air dried lumber is left on the yard during such periods, it will often pick up moisture. Lumber involved in this study was stacked in the spring and early summer of 1956. Daily weather records for 1955 and 1956 show that conditions for drying lumber were generally favorable for rapid drying during this time (fig. 6). In periods less favorable to rapid drying, more degrade, particularly from bluestain and decay, might be expected.

The relatively excellent drying conditions that preceded this study provided surprising results in the speed of drying and uniformity of moisture content. Practically all lumber that had dried 3 weeks or more, regardless of the method of stacking, showed an average moisture content below the 19 percent required by the Southern Pine Inspection Bureau. Individual moisture contents were sometimes high even though the average of the various layers in each type of piling indicated uniformity within the piles (table 4).

Although the data presented in table 4 show average moisture contents below 19 percent, it should not be assumed that all methods give equally satisfactory results. There is considerable variation in different boards in a lumber pile and even between different measurements within single boards. Generally speaking, such variations were least in flat and package piling and greatest in crib and end piling.

Table 4.--Average moisture content by methods of piling and position in pile

Method of piling	Range of seasoning periods	Position in pile 1/			Average for pile
		Top	Middle	Bottom	
	Days	- - - - Percent moisture content - - - -			
Flat piled	33-155	11.66	13.71	15.08	13.64
Package piled	31-104	15.50	15.57	16.14	15.48
End piled	19-36	15.10	16.49	19.15	16.91
Crib piled 2/	20-172	13.43	14.29	15.19	14.29

1/ Average measurement of top 2 layers, center layers, and bottom layers for all methods except end piling, where measurements were made in top, center, and bottom of individual boards.

2/ All measurement made away from laps. Moisture content at laps averaged 33.6 percent. Including laps, average moisture content was 16.58.

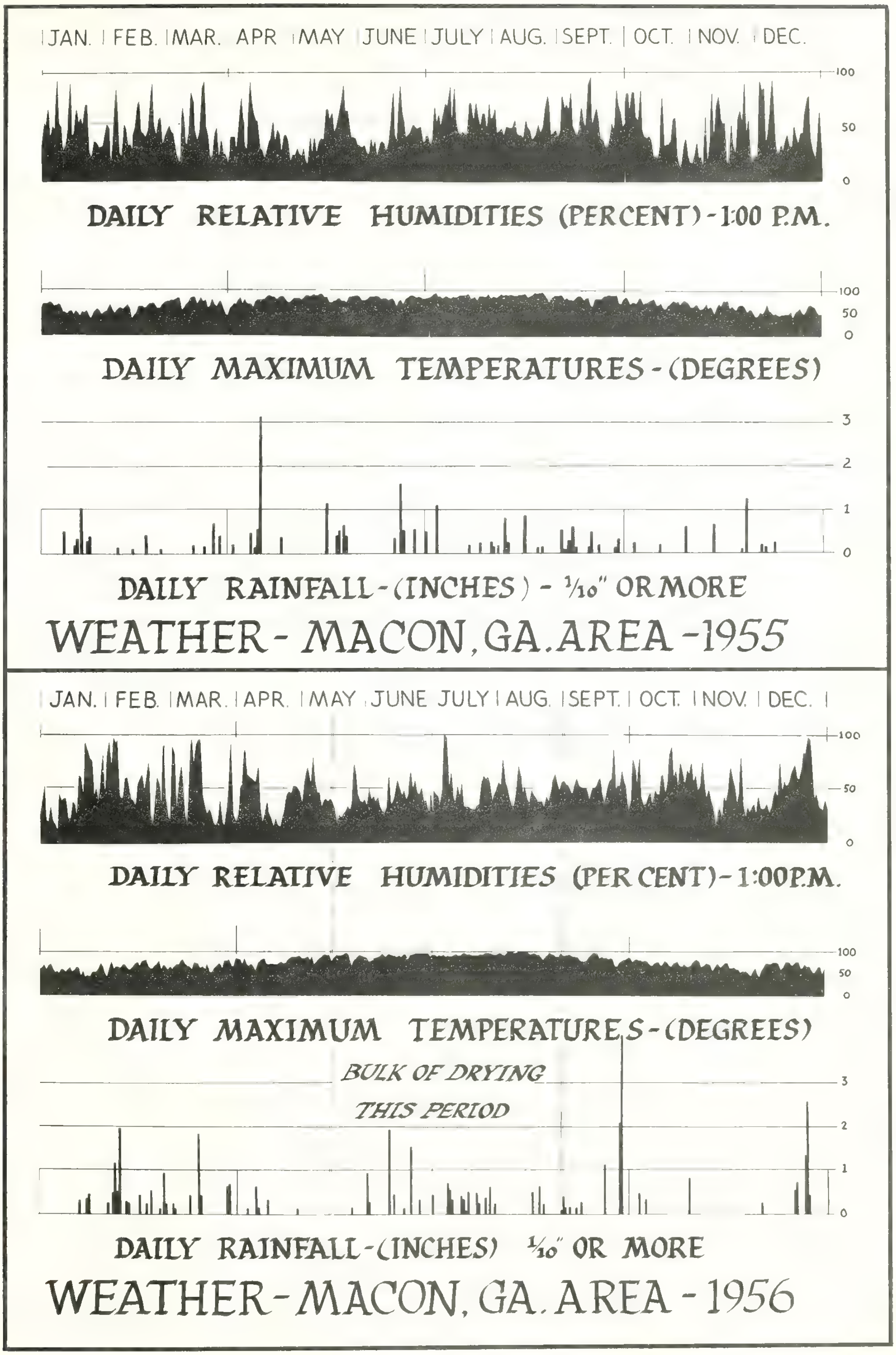

Figure 6.--Relative humidities, temperatures, and rainfall, Macon, Georgia, area, January 1, 1955-December 31, 1956, from Local Climatological Data, U. S. Dept. Com., Weather Bureau, Macon, Ga.

Stain (fig. 7) was by far the most important degrading factor encountered in this study. It comprised almost 85 percent of the total loss in flat piled lumber, 75 percent in end piled, 72 percent in package piled, and 35 percent in crib piled (table 5).

Figure 7.--Bluestain occurring where boards lapped in crib piling. Much of the lumber on this middle Georgia yard was degraded by bluestain.

Table 5.--Loss per thousand board-feet from various causes by four methods of stacking
(In dollars)

Cause	Package piled	End piled	Crib piled	Flat piled	Average all methods
Surface checks	0.31	0.33	0.47	--	0.31
End checks	.09	--	.03	0.31	.05
Stain	3.78	6.83	3.88	22.25	7.46
Decay	.02	--	3.74	--	.35
Crook	.10	.88	.42	.60	.77
Bow	.10	.20	1.22	1.01	.35
Cup	.12	.20	.08	.05	.03
Multiple defects 1/	.12	.90	1.33	1.99	.89
Total all causes	5.21	9.14	11.17	26.21	10.21

1/ Combinations of the above. A board may show stain, crook, and cup, which are impossible to separate on a dollar basis, and so they are lumped here.

The warping defects, crooks, bow, and cup, represent the next most important class of defects and account for an average loss of $1.35 per M board-feet in the samples studied. Twist, a fourth warping defect, occurred to a limited extent in the lumber sampled, but was not sufficiently severe to cause degrade.

Decay was important only in crib piled lumber and occurred where the boards lapped. As indicated by the moisture content of the lapped areas, drying below the fiber saturation point (30 percent) did not occur at most of these lap joints, and if pile stayed up long enough, decay fungi became active.

Checking was relatively unimportant with reference to degrade. It seems that unusually severe drying conditions are necessary to produce degrading checks in southern pine lumber.

Even in flat piles, package piles, and crib piles, where top, center, and bottom section can be delineated, it is difficult to evaluate losses by pile sections with any degree of consistency (table 6). This study, then indicates that for 4/4 pine, the section of the pile in which the lumber was stacked is of little importance in the over-all picture of air seasoning degrade. Since the study was made during a period of very favorable seasoning weather, this statement might not be true if the same lumber had been seasoned at a time when humidities were excessively high and rainfall more abundant.

Table 6.--Loss per thousand board-feet from various causes of degrade, by pile sections
(In dollars)

Cause	Flat pile				Package pile				Crib pile			
	Top	Middle	Bottom	Pile	Top	Middle	Bottom	Pile	Top	Middle	Bottom	Pile
Surface checks	--	--	--	--	1.24	0.20	2.31	0.31	--	0.45	1.42	0.47
End checks	1.05	0.23	--	0.31	.10	.09	--	.09	0.28	--	.37	.03
Stain	16.83	23.00	19.45	22.25	6.63	3.68	2.25	3.78	3.47	3.75	7.56	3.88
Decay	--	--	--	--	--	--	.63	.02	2.50	3.72	5.86	3.74
Crook	--	.70	--	.60	1.07	.66	--	.67	--	.47	--	.42
Bow	.69	1.09	--	1.01	.39	--	3.12	.10	6.43	.98	--	1.22
Cup	.46	--	--	.05	.09	.12	--	.12	--	.09	--	.08
Multiple defects	2.51	2.02	--	1.99	1.99	--	1.00	.12	6.15	1.12	--	1.33
All causes	21.54	27.04	19.45	26.21	11.51	4.75	9.31	5.21	18.83	10.58	15.21	11.17

RECOMMENDATIONS

Reduction of Bluestain

Although stain caused by fungi is the most serious degrading factor in pine air seasoning yards in Georgia, it is the easiest to eliminate. Stain fungi are active in pine lumber under warm, humid conditions when the moisture content of lumber is above 20 percent. Stain can be eliminated by reducing the moisture content on board surfaces below 20 percent immediately after it is sawn, or by dipping the fresh-sawn lumber in an antistain chemical.

Rapid air drying is the method most commonly tried and usually the most unsatisfactory. Crib piling, end piling and other methods of relatively open stacking are primarily to expedite drying. These methods fail in humid weather or where other factors such as lapped boards, close-piled lumber, inadequate foundations (fig. 8), or weeds and debris (fig. 9), retard circulation and prevent fast drying.

When dipping is delayed more than 24 hours after sawing, stain may occur because the chemicals did not penetrate as deep as the fungi, which will continue to grow below the treated surfaces. Furthermore, the chemical is good for only a few months, and subsequent rewetting of the lumber can also produce stain. It is therefore important to stack lumber properly for rapid drying even though it has been promptly dipped.

The cost of dipping varies from 20 to 50 cents per M board-feet of lumber, depending on the dipping equipment and chemicals used. A number of good commercial products for the process are listed in a recent publication.[3/]

Reduction of Warp

It is true that leaning pine trees contain compression wood on the underside of the lean and this abnormal wood warps badly in drying (fig. 10). Little can be done to prevent this type of warp, but fortunately not much of it occurs. Most warp occurs in southern pine as a result of the way it is stacked (fig. 11).

Warp can be controlled by building piles uniformly with an even distribution of weight on all boards. This means firm foundations (fig. 12) with supports under the lumber at 2-foot intervals for 1-inch stock, and 4-foot intervals for thicker stock. All stickers and bolsters should be well-aligned with the foundation timbers and with each other (fig. 13). Stickers and lumber should be uniform in thickness. Piles should be roofed to prevent rainwater and sunshine from contributing to warp in the upper courses. Lumber should be box piled so that no boards extend beyond the pile ends, and stickers should be within 2 inches of the ends of the boards. Stickers should not be more than 2 feet apart for 4/4 lumber or more than 4 feet apart for thicker lumber.

3/ Forest Utilization Service Release No. 10, "The Occurrence and Control of Bluestain in Lumber," available upon request from the Forest Utilization Service, P. O. Box 1183, Macon, Georgia.

Figure 8.--Foundations made of solid cribbing act as barriers to the escape of moisture-laden air from the pile.

Figure 9.--Excessive weeds and lumber in alleys retard drying and harbor decay and bluestain fungi.

Figure 10.--Pine boards containing compression wood often warp badly no matter how the lumber is stacked to dry.

Figure 11.--The result of careless stacking on a pine yard in south Georgia.

Figure 12.--This foundation made of treated timbers permits adequate circulation of air and provides a firm support for the flat piled lumber.

Figure 13.--Boards adjacent to unaligned stickers or bolsters warp badly.

Reduction of End and Surface Checks

Although losses from checking in southern pine lumber constitute a very small part of the total seasoning loss, degrading surface checks and end checks or splits will occasionally develop under conditions extremely favorable to very rapid drying. To prevent this degrade, the operator has recourse to two remedial measures. One is to roof the pile so that constant wetting and drying of the boards in the top courses will be avoided. The second is to place the stickers at the ends of the boards or not more than 2 inches from the ends, thus reducing end drying and largely preventing end checks from extending beyond the stickers.

Measures to Expedite Drying

If is often necessary to dry lumber fast to avoid degrade from bluestain or to meet customer demand. This can be done in several ways: (1) by stacking in narrow, package piles with ample space between stacks; (2) by crib piling with dry stickers and using enough foundation supports to avoid warping; (3) by using chimneys in flat piles with adequate distance between piles; and (4) by general measures such as more distance between stacks, additional space between individual boards (fig. 14), higher and more open foundations, thicker stickers, and clean, well drained yards that are free from obstructions such as trees and buildings.

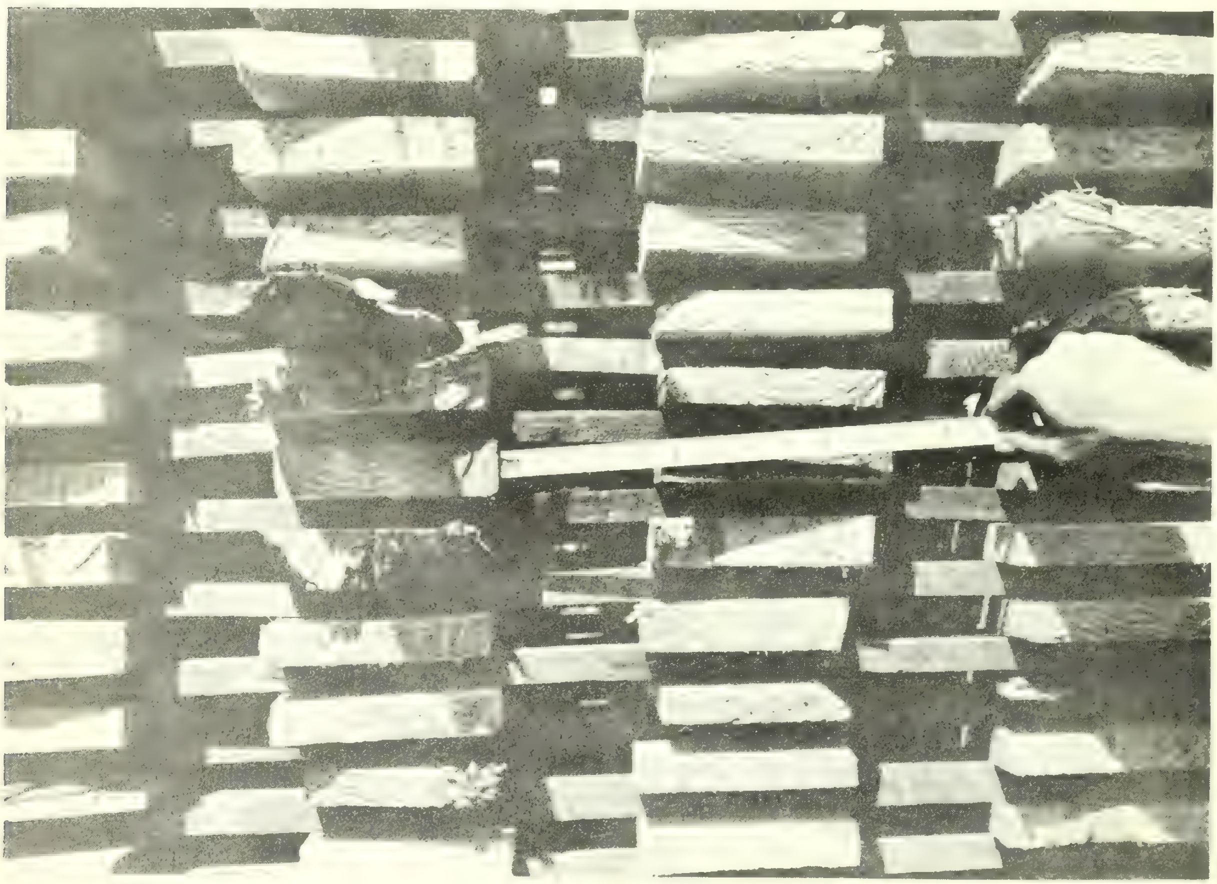

Figure 14.--With adequate spacing between boards, lumber dries faster.

Checklist of Good Seasoning Practices

Each air seasoning yard presents problems peculiar to itself, and the answers to rapid air drying with a minimum of degrade are not necessarily the same for all yards. There are, however, certain fundamental factors that must be considered regardless of location, species, or methods of piling. Included in a list of such factors are the following:

(1) Well-drained and well-aerated yards free of weeds and debris.

(2) Foundations at least 12 and preferably 18 inches high, made of durable material and so constructed that they do not retard the circulation of air throughout the pile (fig. 12).

(3) Rain- and sun-tight covers, particularly over select grades of lumber (fig. 15).

(4) Dry stickers of uniform size placed between courses by means of a sticker guide rack so that they are well aligned (fig. 16).

(5) Spacing of stickers not more than 2 feet apart in 4/4 lumber and 3 feet apart in thicker lumber. End stickers should be within 2 inches of the board ends.

(6) Careful placement of bolsters between the units of a package pile so that they are in line with stickers (fig. 17).

(7) Spacing of individual boards at least an inch apart in flat piles up to 6 feet in width, and construction of flues or chimneys in wide, flat piles.

(8) Rear alleys no less than 4 feet and side alleys no less than 3 feet in width (fig. 18).

(9) Smooth, firm, road surfaces to expedite operation of lumber-handling equipment and to reduce hazards of yard operation.

(10) Dipping in antistain solution before the lumber becomes infected.

The adoption of these practices by concentration yard operators would eliminate much of the unnecessary loss from seasoning degrade not only in Georgia, but wherever lumber is air dried.

Figure 15.--These covers are substantially made of low-grade lumber. They are placed on the top package before this package is lifted in place. Without covers, lumber in the top courses is often degraded.

Figure 16.--This sticker guide rack costs little to make, yet assures alignment of stickers on one side. A portable second side can be added.

Figure 17.--Mechanized yards must be well planned so that lumber-handling equipment can be operated safely and efficiently.

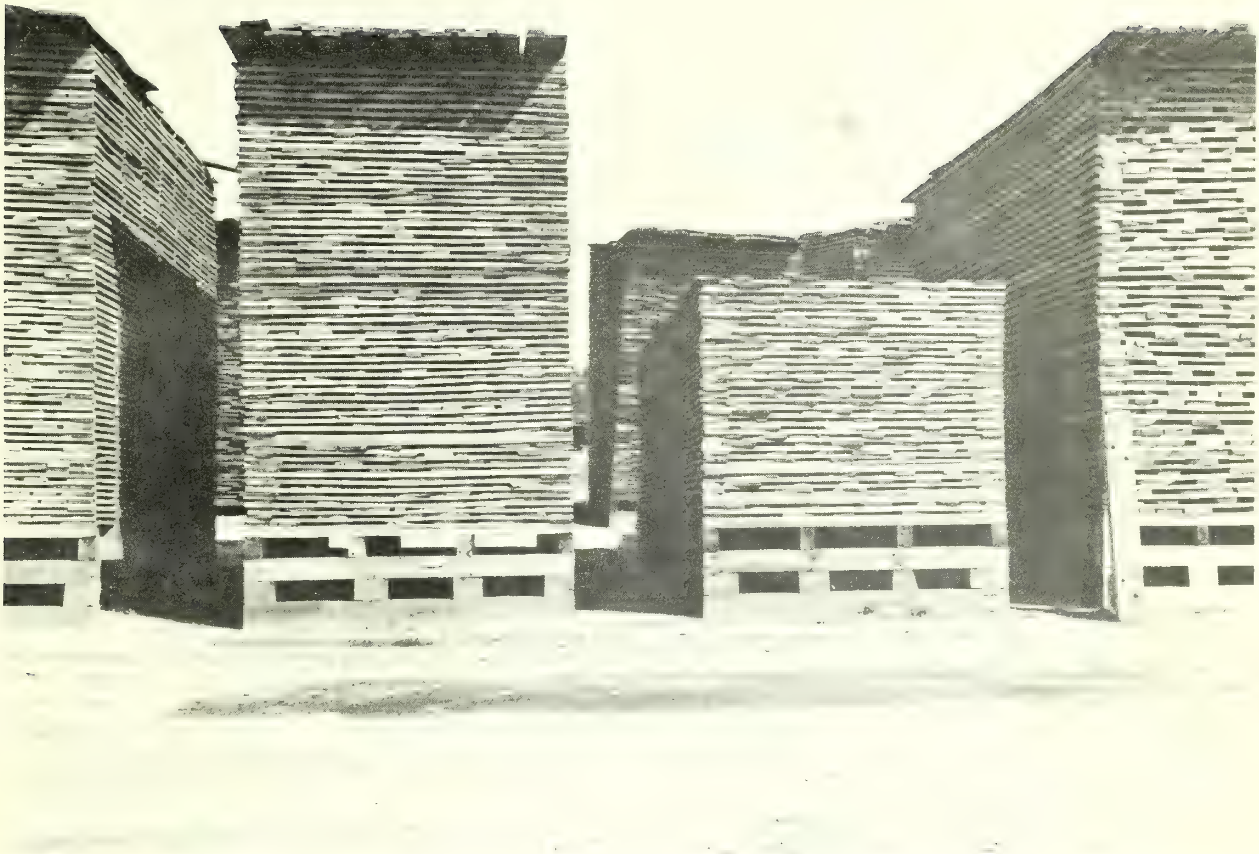

Figure 18.--These well-made stacks of flat piled lumber dry rapidly with a minimum of seasoning degrade.

CONCLUSIONS

Losses from air seasoning mixed grades of 4/4 pine lumber involved in this study in Georgia ranged from $5.21 per M board-feet for package piled to $26.21 per M board-feet for flat piled lumber. These losses are sufficiently serious in most yards to justify remedial measures.

With proper practices, it should be possible to eliminate most of these losses and thus effect an appreciable savings to the lumber yard owners in the state. This potential added income from better seasoning practices would offset, in part at least, the recent increase in labor cost and the steadily rising cost of stumpage. In fact, the money saved by adopting improved practices in air seasoning lumber might well be the major factor in determining whether or not many Georgia mills continue to operate.

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Silvical Characteristics of Scarlet Oak

by

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SILVICAL CHARACTERISTICS OF SCARLET OAK
(Quercus coccinea, Muenchh.)

by

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Scarlet oak (Quercus coccinea Muenchh.) sometimes is called Spanish oak and occasionally black oak. Both the preferred common name and the scientific name are derived from the brilliant scarlet color of its autumn leaves.

RANGE

The natural range of scarlet oak includes the whole or a part of all states east of the Mississippi River except Wisconsin, Florida, and perhaps Mississippi (fig. 1). Its range west of the Mississippi River is limited to southeast Missouri (16). It is frequently and successfully planted outside its natural range as an ornamental tree.

USES

Betts (1) indicates scarlet oak is a very important timber species in the Alleghanies, and it ranks seventh nationally among the oaks. It is discriminated against by the sawmiller because of frequent and severe borer damage and decay, but when cut from a good site its yield of high quality lumber approaches that of northern red oak (3).

HABITAT CONDITIONS

CLIMATIC

The entire range of scarlet oak is classed as humid (26). Average annual precipitation over its range varies from 30 inches in the West to 55 inches in the Southeast and at the higher elevations. Maximum elevation for scarlet oak as reported by Sargent (21) is 5,000 feet and this occurs in the Southern Appalachians. However, it is usually found at elevations under 3,000 feet (24).

EDAPHIC AND PHYSIOGRAPHIC

Scarlet oak occurs on a wide variety of soils within its range. The great soil groups with which it is most frequently associated are the gray-brown podzolic soils in the North and the red and yellow podzolic soils of the South (27). Scarlet oak is most often found on average to less than average sites. It is a typical upland oak species of the ridges and upper and middle slopes. However, it makes its best growth on moist, well-drained cove soils.

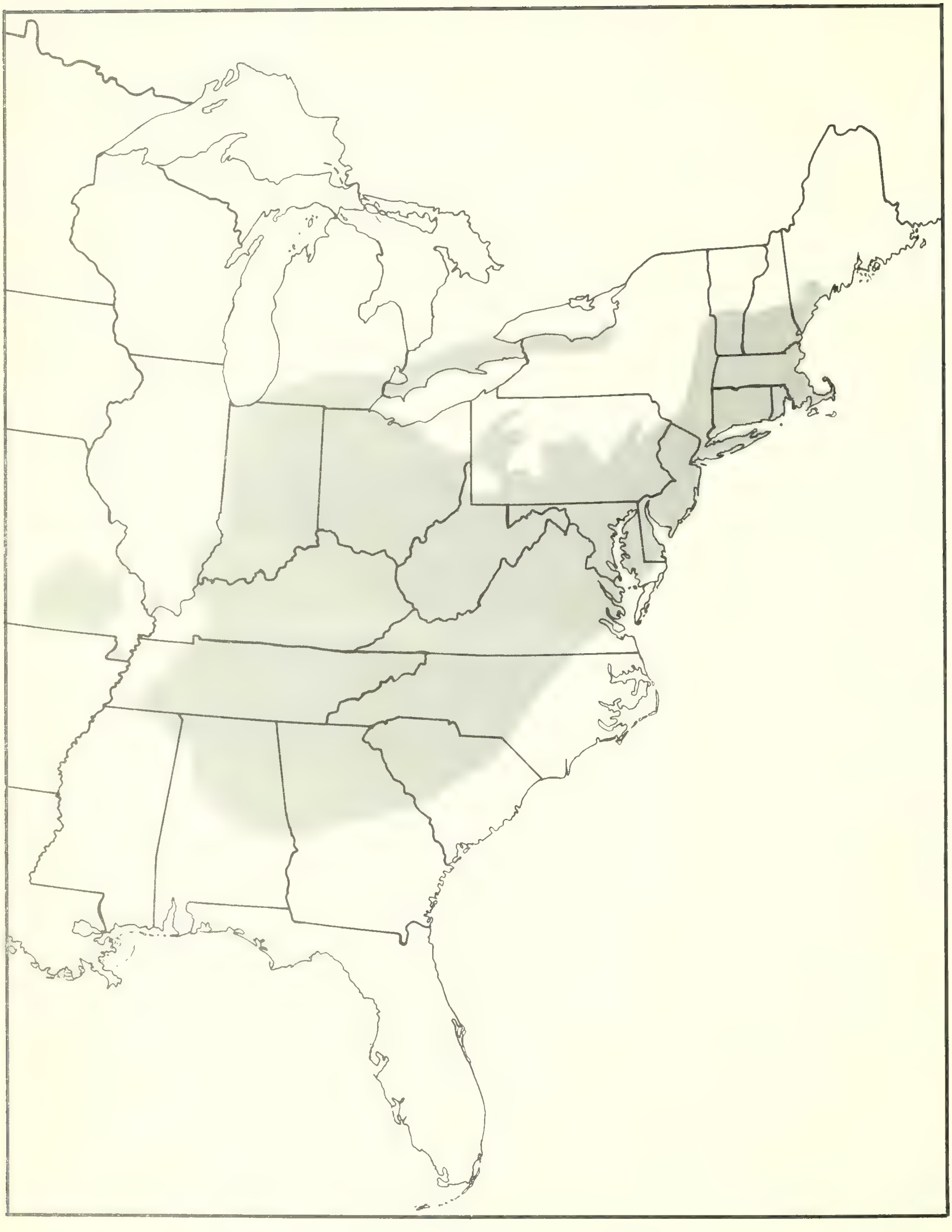

Figure 1.--Botanical range of scarlet oak.

In a study of soils and site in the Southern Appalachians, Doolittle (6) found that the site index of scarlet oak ranges from 37 to 91 feet (at 50 years). Trimble and Weitzman (25) reported that this species has the highest site index ratio (1.03) of the five common oak species found in the northern Appalachians. Although this species apparently regenerates and competes best on the poorer and lighter soils, Doolittle's study shows that site index of this species increases with increasing depth of A horizon, decreasing amounts of sand in the A horizon, and with lower positions on the slope. Position on slope was also considered an important factor by Trimble and Weitzman along with aspect, grade of slope, and depth of soil to bedrock.

Although its place in succession is not clear, scarlet oak probably approaches climax on dry soils (24). Due to its hardiness, scarlet oak is planted on an even wider variety of soils than those on which it grows naturally.

BIOTIC

Scarlet oak is a component of 15 of the 106 cover types listed for North America (24). It is the major species in its own type. With it are found black oak (*Quercus velutina*) and southern red oak (*Quercus falcata*) as coordinate species. Other associated species include chestnut oak (*Quercus prinus*), white oak (*Quercus alba*), post oak (*Quercus stellata*), the hickories (*Carya* spp.), pitch pine (*Pinus rigida*), shortleaf pine (*Pinus echinata*), Virginia pine (*Pinus virginiana*), black gum (*Nyssa sylvatica*), sweetgum (*Liquidambar styraciflua*), and black locust (*Robinia pseudoacacia*).

Small patches of almost pure black oak are occasionally found within the type. The type grades into post oak-blackjack oak on very dry sites (24).

The more common minor trees and shrubs found with scarlet oak include: dogwood (*Cornus florida*), mountain-laurel (*Kalmia latifolia*), sourwood (*Oxydendrum arboreum*), and blueberries (*Vaccinium* spp.)

Scarlet oak acorns are a choice food for eastern gray squirrels (*Sciurus carolinensis*), chipmunks (*Tamias striatus*), mice (*Peromyscus* spp.), and birds, especially the blue jay (*Cyanocitta cristata*) (14).

LIFE HISTORY

SEEDING HABITS

Like most oaks, scarlet oak flowers sometime in April or May, depending on latitude, elevation, and variations in weather. Two full growing seasons are required between fertilization and maturity for acorns.

Good seed crops were observed every 3 or 4 years by Downs and McQuilkin (7) in the Southern Appalachians, whereas the Woody-Plant Seed Manual (29) indicates an irregular period of good seed crops. Burns et al. (2) concluded from their Missouri study that oak seed production varied

greatly from year to year for all five oaks studied, but that scarlet oak was the most variable among black, white, post, blackjack, and scarlet oaks. They also found that scarlet oak was the most prolific seeder in the years that it did have a good crop. They failed to find, during their 6-year study, any clearly defined cycles of seed production for any of these oaks, but concluded that a good crop appears at least once every 5 years for each species. Downs and McQuilkin found that seed production increased rapidly with tree size up to 20 inches d.b.h. and then levelled off for this species in the Southern Appalachians. Burns et al. could not tie seed production to measurable tree characteristics. Scarlet oak is the last of five species studied to lose its acorns in the fall, according to Downs and McQuilkin.

Downs and McQuilkin (7) also found that from 20 to 60 percent of the annual crop consisted of sound acorns. The higher proportion accompanies the years of greatest seed production. Birds and squirrels were responsible for 44 percent of the total damage to acorns of all species while the acorns were still on the tree, and insects were responsible for the remaining 56 percent of the total. A similar degree of insect damage was reported by Burns et al. (2). After seedfall, insects again did the most damage; in the case of scarlet oak the sources of damage to acorns are as follows: 36 percent from birds and 64 percent from insects (7). Of those sound acorns reaching the ground, Downs and McQuilkin found a higher proportion were consumed by deer than by squirrels. Korstian (14), in his Southern Appalachian study, found three groups of insects responsible for acorn damage: nut weevils (Curculio spp.), moth larvae (Valentina glanduella), and gall cinipids (Cynipidae). He also reported that insect injury to acorns was higher in the black than in the white oaks. Of these insects, Downs and McQuilkin considered nut weevils the most harmful.

In seeding or nursery practice, fall seeding is recommended. If held till spring, the acorns should be stratified (29).

Scarlet oak seedlings are very susceptible to fire damage (14). This weakness coupled with a dry environment helps explain the high mortality or severe damage to seedlings even from light ground fires.

VEGETATIVE REPRODUCTION

Roth and Sleeth (20) found that scarlet oak stumps in the Appalachians produced sprouts to greater ages and to larger sizes than the other oaks. In southern New Jersey Little (17) also found that scarlet oak sprouts were the most vigorous of all oaks studied, and in common with associated oaks, regeneration by sprouting was very successful when stumps were small, but decreasingly so as size and age increased to sawtimber size.

Roth and Sleeth reported that 28 percent of the scarlet oak sprouts in their study had butt rot, and that sprouts from large stumps were more subject to butt rot than sprouts from small stumps. As the sprouts grow older, the rot spreads and may weaken the trees to a point where they break off during periods of high winds.

SEEDLING DEVELOPMENT

In 1927 Korstian (14) proved that a light covering of forest litter was helpful to the germination of acorns. He also found that no litter and too deep a covering were not as favorable as a light covering. Partial cutting provides more favorable conditions for germination than does seed-tree cutting, according to Downs (7). He recommended a 2-cut shelterwood method, with the first cut to provide for germination and the second cut to be made as soon as the seedlings are established to allow for better growth.

SAPLING STAGE TO MATURITY

Scarlet oak is a medium-size tree, normally maturing at 60 to 80 feet in height and 2 to 3 feet in diameter. Maximum size is 100 feet tall and 4 feet in diameter (10).

Scarlet oak is a tree of rapid growth and early maturity. Hursh and Barrett (12) found that it ranked next to yellow-poplar in rate of diameter growth in their north Georgia study. Campbell's Southern Appalachian study (4) confirmed this rapid growth rate, but both scarlet oak and yellow-poplar were outgrown by northern red oak. However, on poor sites scarlet oak probably grows more rapidly than any other species. McIntyre's (19) study of growth rates among the oaks in Pennsylvania showed for the smaller sizes of sawtimber that black oak grew 0.8 inch radially in 10 years and exceeded northern red, scarlet, white, and chestnut oak, in that order.

For survey purposes scarlet oak was grouped with other red oaks (except northern red) by McCormack (18) and the entire group contained about the same volume as chestnut oak, which has the largest volume of any one species in the mountain area of North Carolina. Farther north (in the Alleghanies) it is expected that scarlet might be the major single species (1). Stands of pure scarlet oak on the better dry slopes and ridges produce yields approximately equal to chestnut oak, or an estimated 7,000 board-feet at 80 years (8).

Schnur's study (23) shows that mean annual cubic growth for the oaks in general culminates at about 50 years for all sites, and ranges from a high of 70 cubic feet for site 80 to a low of 25 cubic feet for site 40. The mean annual board-foot growth culminates at 75 years of age on the better sites and at 100 years for the poorer ones. Annual board-foot growth per acre ranges from a high of 335 for site 80 to a low of 90 for site 40. Cubic and board-foot volume tables for various tree heights and diameters are also shown for each of the oak species in this same publication. Total yields per acre in cubic feet and board-feet were adapted from Schnur's bulletin and are shown in table 1.

Economic maturity for scarlet oak drops rapidly from 23 inches d.b.h. for a tree of vigor class 1 down to 18 inches for a tree of vigor class 3 (4).

Because of its thin bark, scarlet oak is very susceptible to fire damage; if not killed outright, the tree is usually injured so that sap or heart rots enter.

Table 1.--Mixed oak yields per acre, by site index class

Total age (Years)	Site index of 40 feet		Site index of 60 feet		Site index of 80 feet	
	Cubic feet	Board-feet	Cubic feet	Board-feet	Cubic feet	Board-feet
20	20	0	170	0	620	350
40	680	600	1,580	3,200	2,610	8,600
60	1,420	2,700	2,800	9,700	4,160	18,600
80	2,050	5,900	3,730	15,650	5,340	27,250
100	2,590	9,200	4,480	20,900	6,380	34,400

In a laboratory study by Scheffer et al. (22) it was found that wood from the red oak species was more susceptible to decay than wood from the white oaks, but that scarlet oak wood was no more susceptible than the wood of other red oaks. In living trees, however, heart rot becomes critical in scarlet oak at an early age because of persistent branch stubs, which allow heart rots to enter.

Scarlet oak is also susceptible to oak wilt (*Endoconidiophora fagacearum*) (28). Trees attacked by this fungus may die within a month after the first symptoms become evident. Hepting (11) lists this oak as being subject to cankers of *Nectria* spp. and *Strumella coryneoidea*. These diseases are especially severe from Virginia northward.

Because insect pests are so numerous, only the more common and serious ones will be discussed. The spring cankerworm (*Paleacrita vernata*), the fall cankerworm (*Alsophila pometaria*), and the forest tent caterpillar (*Malacosoma disstria*) (5, 13) are defoliators which do no great damage in one year's time, but when the outbreaks last for several years, as they frequently do, the affected trees are greatly weakened and suffer loss in growth. Occasionally these repeated attacks result in death of the affected tree. Walking stick (*Diapheromera femorata*) is another defoliator which feeds largely on the oaks, particularly in the Lake States. All of the defoliator larvae can be destroyed in the feeding stage by the aerial application of a DDT spray (15). The 2-lined chestnut borer (*Agrilus bilineatus*) is a secondary pest of the oaks following drought, fire, or other unfavorable changes in the tree's habitat.

On a basis of volume of logs damaged by insect attack in eastern Kentucky, Hay and Wootten (9) found that scarlet oak ranked next to chestnut oak in severity of damage. Larvae of the carpenter worms (*Prionoxystus* spp.) tunnel in all directions in both heartwood and sapwood of oak trees; consequently they do much damage to the lumber. Members of two ambrosia beetle genera, *Platypus* and *Xyleborus*, are very harmful to freshly damaged or cut trees.

SPECIAL FEATURES

The brilliant autumn coloring of the leaves of scarlet oak makes it a choice ornamental over most of eastern United States. The bark is fairly high in tannin content but the tree has not been commercially used for this product.

RACES AND HYBRIDS

Sargent (21) and Little (16) list two crosses or hybrids of scarlet oak. One is *Quercus* x *robbinsii* Trel. (*Quercus coccinea* x *ilicifolia*), and the other is *Quercus* x *benderi* Baenitz (*Quercus coccinea* x *rubra*). Little also notes that *Quercus* x *robbinsii* may be hard to distinguish from *Quercus ellipsoidalis*.

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Silvical Characteristics of Flowering Dogwood

by

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SILVICAL CHARACTERISTICS OF FLOWERING DOGWOOD

(*Cornus florida* L.)

by

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Flowering dogwood (*Cornus florida* L.) is sometimes called cornel or boxwood (22). Dogwood grows from extreme southwestern Maine west to extreme southern Ontario, southern Michigan, Illinois, and eastern Kansas south to eastern Texas and north-central Florida (fig. 1) (15, 30, 36, 37). The commercial range includes the southern Mississippi Valley, the Southern Appalachian Mountain Region, and most of the southern pine belt (5).

USES

About 90 percent of the dogwood cut is used by the textile industry for shuttleblocks. Minor uses of the wood are for specialty items such as pulleys, jewelers and engravers blocks, mallet heads, and charcoal. The bark, which contains a quinine-like substance, is astringent and high in tannic acid content. Dogwood is widely planted because of its ornamental and game-food values (9, 37).

HABITAT CONDITIONS

CLIMATIC

The amount of annual precipitation within the range of dogwood varies from a low of 30 inches in the north to a high of 80 inches in the Southern Appalachians. Warm-season precipitation ranges from about 20 inches in southern Michigan to around 34 inches in northern Florida, and annual snowfall ranges from none in Florida to 50 or more inches in the North. Average annual temperature is 70° F. in the South and 45° in the North, while temperature extremes show a high of 115° and a low of -30°. The growing season varies in length from 160 days in southern Michigan to 300 or more days in northern Florida (35, 39).

EDAPHIC

Dogwood occurs on a variety of soils ranging from deep, moist soils along streambanks to well drained, light upland soils (36). Dogwood occurs most frequently on soils of pH 6 to 7 (2, 26). The most important great soil groups included in the range of flowering dogwood are red and yellow podzolic, gray-brown podzolic, brown podzolic, and alluvial soils (6).

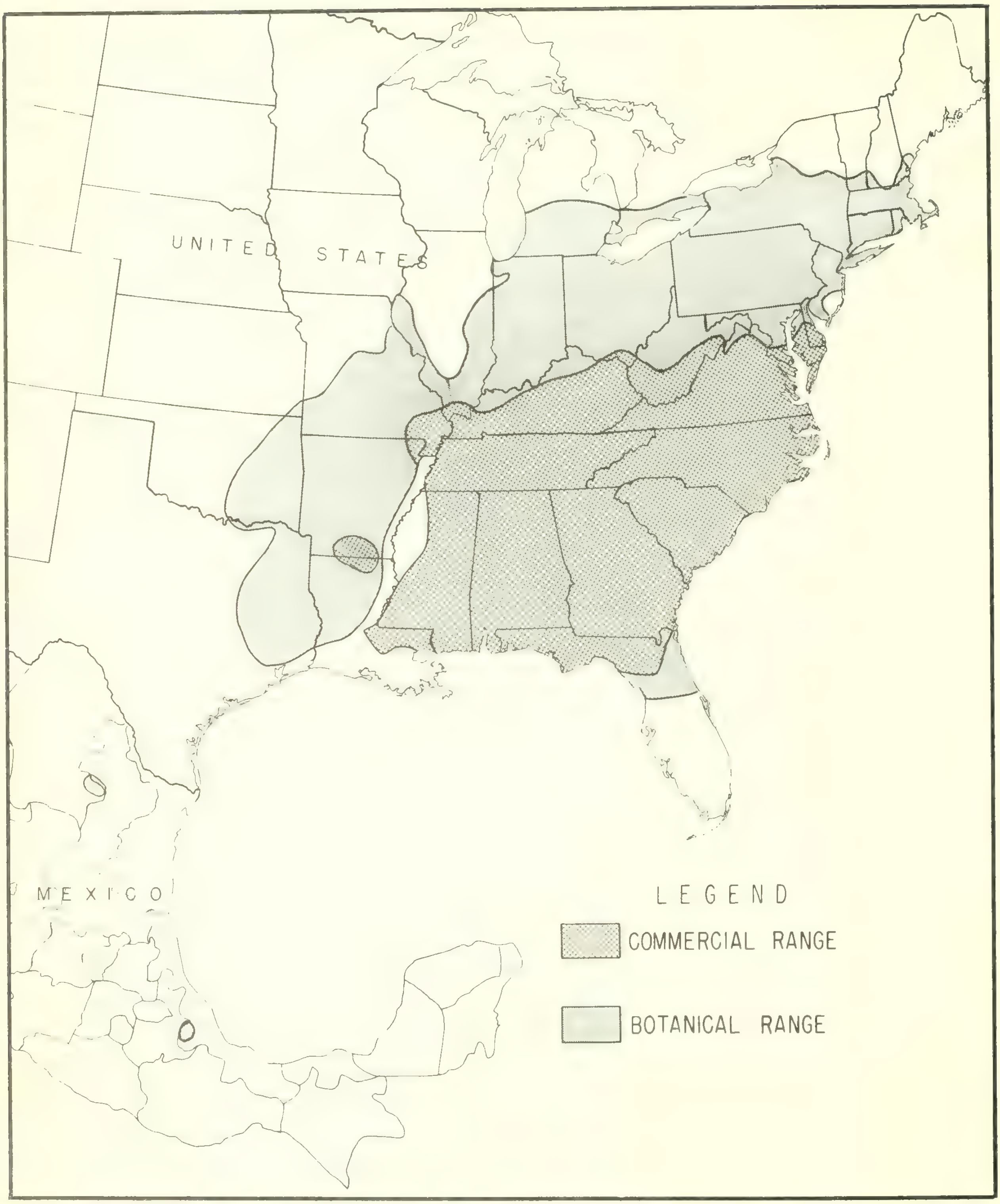

Figure 1.--Botanical and commercial range of flowering dogwood (Cornus florida).

The survival of dogwood seedlings is much lower on heavy soils than on light ones (13). In New England, dogwood occurs mainly on soils of medium water-holding capacity (10). On cutover loblolly pine (*Pinus taeda*) lands in the Virginia Coastal Plain, it was found that the species was virtually absent on poorly drained, heavy soils. As drainage improved and soils became lighter, the frequency of dogwood in the stand increased. The following tabulation illustrates how the frequency of occurrence of five hardwood species varied with major soil differences (41):

Species	Poorly drained plastic (Percent)	Well drained plastic (Percent)	Well drained friable (Percent)
Sweetgum (*Liquidambar styraciflua*)	41.5	39.0	26.0
Red maple (*Acer rubrum*)	43.0	39.0	26.0
Red oaks (*Quercus* spp.)	12.0	10.0	21.0
Dogwood	0.5	5.0	15.0
Waxmyrtle (*Myrica cerifera*)	3.0	7.0	12.0
Total	100.0	100.0	100.0

The role of dogwood as a soil improver is of increasing interest. The litter contains 2.0 to 3.5 percent calcium on an ovendry basis (8, 24). By comparison, the litter of black oak (*Quercus velutina*), sweetgum, shortleaf pine (*Pinus echinata*), loblolly pine, and white oak (*Quercus alba*) has only 0.4 to 1.1 percent calcium. In the North Carolina Piedmont the abundance of dogwood in the latter stages of pine succession materially improves soil fertility (8).

In addition to being an important source of calcium, dogwood litter decomposes more rapidly than that of other species, thus making its mineral constituents more readily available (8). It also ranks high in antacid buffering capacity. The decomposition factors for the litter of dogwood and several other species are listed below:

Species	Decomposition factor
Flowering dogwood	92
Hickory (*Carya* spp.)	31
Yellow-poplar (*Liriodendron tulipifera*)	19
Eastern redcedar (*Juniperus virginiana*)	19
White ash (*Fraxinus americana*)	18
Sycamore (*Platanus occidentalis*)	9
Northern red oak (*Quercus rubra*)	8
White and black oaks (*Quercus* spp.)	7

Decomposition factor = $\frac{N \times Ca \times 10}{H+}$ where N = weight of total nitrogen in the leaf, Ca = weight of total calcium, and H+ = weight of free H+ ions when 5 grams of litter are in equilibrium with 100 ml. of .05 N HCl. This

factor is positively correlated with decomposition under field conditions, although failure to include content of tannins and resinous matter in the equation results in high values for redcedar and the oaks.

PHYSIOGRAPHIC

In the Southern Appalachians, the optimum elevation for dogwood is 1,000 to 4,000 feet (17). It grows well on flats and on lower and middle slopes but not very well on upper slopes or ridges.

On the Piedmont Plateau of North Carolina, dogwood is a characteristic understory tree in upland stands of loblolly pine (24). As these stands progress over into the hardwood climax, dogwood remains an important subordinate species. Dogwood is also one of the most numerous species in the understory of bottomland loblolly pine and hardwood stands.

In southern Kentucky, dogwood is a common tree on broad ridge tops of the Cumberland Plateau escarpment. It occurs frequently on deep, well-drained upland sites in the Ozarks, especially on north and east aspects. In the New Jersey Piedmont, dogwood is an important understory species (4).

BIOTIC

Although flowering dogwood is specifically mentioned in only two forest types, Number 41 scarlet oak, and Number 52 white oak-northern red oak-hickory, it occurs in a number of others, always as a subordinate species. It is found growing throughout most of the eastern United States in association with many other hardwoods and conifers.

The species with which dogwood is associated in types Nos. 41 and 52 are (32):

1. Scarlet oak, No. 41. Scarlet oak (*Quercus coccinea*) predominates. The associated species are black oak, southern red oak (*Quercus falcata*), chestnut oak (*Quercus prinus*), white oak, post oak (*Quercus stellata*), hickories, pitch pine (*Pinus rigida*), blackgum (*Nyssa sylvatica*), sweetgum, black locust (*Robinia pseudoacacia*), shortleaf pine, and Virginia pine (*Pinus virginiana*).

2. White oak-northern red oak-hickory, No. 52. The three types species predominate. In southeastern Pennsylvania, associates are yellow-poplar, pignut hickory (*Carya glabra*), shagbark hickory (*Carya ovata*), mockernut hickory (*Carya tomentosa*), white ash, red maple, beech (*Fagus grandifolia*), and blackgum. This type is found at elevations of 500 to 2,000 feet on upland soils where the moisture supply is reasonably good but not excessive.

Dogwood seed is eaten by many species of birds including various songbirds, ruffed grouse (Bonasa umbellus), bob white quail (Colinus virginianus), and wild turkey (Meleagris gollopavo). It is also attractive to squirrels (Sciurus spp.), chipmunks (Tamius striatus), and cotton tail rabbits (Sylvilagus floridanus) (38). The young shoots are a preferred food of white tail deer (Odocoileus virginianus).

LIFE HISTORY

PHENOLOGY

Average dates for the beginning of flowering, leafing, seed ripening, seedfall, and leaf fall in the northern and southern portions of the dogwood range are as follows (21):

1. Flowering and leafing: April 12 in the South to May 25 in the North.

2. Seed ripening: September 15 in the South to October 15 in the North.

3. Seedfall: October 1 in the South to November 25 in the North.

4. Leaf fall: October 1 in the South to October 30 in the North.

FLOWERING HABITS

The head of the flower bud appears in the summer borne between the upper pair of lateral leaf buds. The involucral scales open early the next spring, forming a showy, flat, corolla-like cup 3 to 4 inches in diameter. The small, perfect flowers are in dense, cymose heads (30). Flowers have been observed on trees of sprout origin which were 6 years old, 3/4 inch in diameter at the stump, and 4 feet tall.

SEEDING HABITS

The bright red, mature fruit of flowering dogwood is ovoid, $\frac{1}{4}$-inch wide and $\frac{1}{2}$-inch long, and crowned with the calyx and style which are both persistent. The fruit has thin, mealy flesh surrounding one or two thick-walled, smooth, slightly grooved seeds (30).

Dogwood produces a good seed crop every 2 years. Seeds produced on isolated trees are frequently hollow, so it is best to make collections from groups of trees. Seed is scattered by gravity, birds, and other animals (37).

VEGETATIVE PROPAGATION

Dogwood is a profuse sprouter. In the Appalachian Mountains of North Carolina, taller, more numerous sprouts were produced following winter fellings than following midsummer fellings (7). In the Coastal Plain of Virginia, height of the sprouts increased with increasing stump diameter, and a 1-inch increase in stump diameter resulted in a 0.3-foot increase in sprout height (41). Epicormic branching is also abundant on this species.[1/]

Dogwood reproduces extensively by layering (24). As much as 100 percent success in the rooting of cuttings can be achieved by treatment with indole 3 butyric acid, indole 3 acetic acid, napthalene acetic acid, or napthalene acetamide (12, 34). Untreated cuttings taken in the spring just at the end of flowering also rooted 100 percent in one study, but failed completely in others. In nursery practice the various clones are commonly propagated by grafting.

SEEDLING DEVELOPMENT

Dogwood seed germinates in the spring after it has lain on the ground over winter. Moist, well-drained, rich loams provide the best seedbed. Nursery germination of the seed ranges from 77 to 85 percent. Freshly gathered seed will not germinate, but germination takes place following moist storage for 100 to 130 days at 0^{o} to 10^{o} C. Seed stored above 15^{o} C. will not germinate (11). Subjecting seed to high hydrostatic pressures will not hasten germination (29). Suggested pretreatment is stratification in sand or peat for 100 to 130 days at 5^{o}C.

Root growth of dogwood seedlings is quite rapid. In one study greenhouse-grown dogwood 6 months old had 3,000 roots with a total length of 168 feet, compared to 800 roots with a total length of 12 feet for loblolly pine (18).

A study of 1-year-old dogwood reproduction in the North Carolina Piedmont showed that soil moisture was the most important factor in seedling survival (13). In another test, also in the North Carolina Piedmont, comparing seedling survival of loblolly pine, shortleaf pine, white oak, and dogwood planted under three different stand conditions (in the open, under pine stands, and on the margin of pine stands), white oak had the best survival in all three locations. The best survival for dogwood was on the stand margin; the best survival for white oak was in the pine stand; and the best survival for the pine was in the open. After four seasons most of the oak and some of the dogwood under the pine stand were still alive but all of the pine seedlings were dead (19).

In a study of 1-0 dogwood seedlings planted in western Tennessee on old field soils of the Susquehanna-Savannah-Ruston group, the first year survival was 80 percent. After the fifth season, however, dogwood survival dropped to 23 percent. Survival was best on north slopes and poorest on south slopes (31).

1/ Doolittle, Warren Truman. Early effects of pruning on the height and diameter growth of sycamore. 56 pp., illus. 1950. (Unpublished M.F. thesis at Duke Univ. School of Forestry.

SAPLING STAGE TO MATURITY

The maximum size for dogwood on good sites is 40 feet tall and 12 to 18 inches d.b.h. (15). Height growth in the Southern Appalachians is fairly rapid the first 20-30 years, but then it practically ceases. Near the northern limits of its range dogwood becomes a many-branched shrub. In western Tennessee, average height of 1-0 seedlings was 2.6 feet 5 years after planting (31). In Jackson County, Florida, it was reported that dogwood reached a breast high diameter of 5 inches in 11 years (1). At Athens, Georgia, the period of rapid diameter growth lasted 80 to 89 days during the growing season; fifty percent of the diameter growth was completed in 40 to 49 days (16).

Minimum merchantable size of dogwood is 4 inches in diameter (inside bark) at the small end of 18-inch bolts. On good sites, yields of 2 cords per acre are possible, but sometimes it takes 15 to 20 acres to grow one cord (5).

Dogwood is very tolerant of shade and is usually found in the understory (3, 24). It reaches maximum photosynthesis at a light intensity of 3,000 foot candles, as does white oak, another tolerant species (20). This ability to carry on maximum photosynthesis at one-third of full sunlight helps to explain why dogwood can survive and grow under a forest canopy.

With such a wide range, dogwood is probably quite tolerant of both high and low temperatures, but it is susceptible to drought. During hot, dry weather dogwood leaves often turn red, curl, and cup. If the drought is prolonged, the leaves may fall and severe dieback of the top follows (23). For example, during a dry spell at Utica, Mississippi, mature dogwood trees were killed.[2/] In north Mississippi dogwood leaves are the first to dry up when a drought begins; on hill sites the drought mortality of dogwood is surpassed only by hickory and overmature blackjack oak. Since it is an understory tree, dogwood receives considerable protection from high winds and glaze storms.

Because of its thin bark, mature dogwood is readily injured by fire (14). In the oak-hickory region, however, this results in an increased proportion of dogwood in the stand because of the profuse sprouting of fire-killed trees. Dogwood is also quite susceptible to flooding. In experiments with potted dogwood seedlings, flooding killed the plants in 1 to 3 weeks (25).

The species is attacked by several insects, most important of which are the dogwood borer (*Thamnosphecia scitula*), the flat headed borers (*Chrysobothris femorata* and *Agrilus cephalicus*), and the dogwood scale (*Chionaspis corni*) (40).

Dogwood is relatively free of disease. Leaf spot (*Cercospora cornicola*) attacks seedlings. Other diseases important mainly on ornamental plantings are (23):

2/ Keppler, William E. Draper Corporation, Asheville, N. C. Personal Interview. December 1956.

1. Basal stem canker, caused by the fungus Phytophthora cactorum, may girdle the tree and is the most common killing disease.

2. Twig blight, caused by the fungus Myxosporium nitidum, sometimes results in dieback of the small twigs.

3. Spotting and dieback of dogwood leaves and flowers is caused by the fungi Botrytis cinerea, and Elsinoe corni. Locally severe shriveling and blackening of the leaves is caused by infections of Ascochyta cornicota, while Septoria cornicola causes less conspicuous leaf spots.

Serious animal injury is uncommon, though dogwood reproduction is often browsed by deer and cottontail rabbits (33).

GENETIC VARIATION

There is no information available on racial variation of dogwood, although with such a wide range racial variation probably exists. Four clones, commonly propagated as ornamentals are (27):

1. Cornus florida f. pendula (Dipp.) Schelle, which has pendulus branches.

2. Cornus florida f. rubra (West.) Schelle, with red or pink involucral bracts.

3. Cornus florida f. pluribracteata Rehder, with 6 to 8 large and several small bracts on the inflorescence.

4. Cornus florida f. xanthocarpa Rehder, which has yellow fruit.

In addition to these clones the Mexican subspecies, Cornus florida subsp. urbiniana (Rose), which Rickett found in the mountains of Nuevo Leon and Vera Cruz, differs from subspecies florida in its greyer twigs and larger drupes. The relative hardiness of the two subspecies is unknown (28).

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Agriculture--Asheville

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Silvical Characteristics of Cherrybark Oak

by

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SILVICAL CHARACTERISTICS OF CHERRYBARK OAK

(*Quercus falcata* var. *pagodaefolia* Ell.)

by
Thomas Lotti
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Cherrybark oak (*Quercus falcata* var. *pagodaefolia* Ell.), also known as bottomland red oak, Elliot oak, red oak, swamp red oak, and swamp Spanish oak, is found in the Coastal Plain from New Jersey and Maryland south to northern Florida and eastern Texas, and north in the Mississippi Valley to southeastern Missouri, and southern Indiana (6).

HABITAT CONDITIONS

CLIMATIC

Cherrybark oak grows in a humid, temperate climate characterized by hot summers and mild, short winters (11). Through a major part of the tree's commercial range, the growing season extends from 230 to 290 days, average annual temperature from 65° to 70° F., and average annual precipitation from 50 to 60 inches. Within this same area the average annual maximum temperature is about 100° F., and the average annual minimum approximates 15°. About half the rainfall occurs during the period April to September, inclusive. Average noonday relative humidity is about 60 percent in mid-July (12).

EDAPHIC AND PHYSIOGRAPHIC

The tree is widely distributed on the best loamy sites in first bottoms and on well drained terraces and colluvial sites associated with both large and small streams of the Southeastern Coastal Plain and the Mississippi Delta (8). It develops best on a loamy well-drained soil. Although uncommon on clay soils, it is generally of good form and quality on the better drained locations but very inferior where drainage is poor (9).

BIOTIC

Cherrybark oak is represented in two cover types as defined by the Society of American Foresters (10). One of these is the beech-southern magnolia type, a transitional climax (2). In this association American beech (*Fagus grandifolia*) is the indicator species and is often the most abundant. Southern magnolia (*Magnolia grandiflora*) and a great variety of other moist-site hardwoods occur, among which the most common, in addition to cherrybark oak, are sweetgum (*Liquidambar styraciflua*), blackgum (*Nyssa sylvatica*), yellow-poplar (*Liriodendron tulipifera*), white oak (*Quercus alba*), white ash

Botanical range of cherrybark oak.

(Fraxinus americana), miscellaneous hickories (Carya sp.) and southern red oak (Quercus falcata). This widely distributed type is often found on loess ridges and in ravines and branch bottoms intersecting many of the pine lands in Louisiana, Arkansas, and Mississippi. It is also found in hammocks in southern Louisiana and elsewhere in the Coastal Plain where these occur (10).

The other cover type is named the swamp chestnut oak-cherrybark oak type. Typically the composition varies widely. Cherrybark oak and swamp chestnut oak (Quercus michauxii) are often only indicator species, although they may be the most abundant of the oaks which are predominant. Other prominent associates are white ash, shagbark hickory (Carya ovata), shellbark hickory (Carya laciniosa), mockernut hickory (Carya tomentosa), and bitternut hickory (Carya cordiformis). Chief associates are blackgum, white oak, Delta post oak (Quercus stellata var. mississippiensis), Shumard oak (Quercus shumardii), and on first bottom ridges sweetgum may be important. Minor associates include southern red oak, southern magnolia, yellow-poplar, American beech, willow oak (Quercus phellos), water oak (Quercus nigra), post oak (Quercus stellata), American elm (Ulmus americana), winged elm (Ulmus alata), swamp hickory (Carya leiodermus), and nutmeg hickory (Carya myristicaeformis) and occasionally loblolly pine (Pinus taeda) and spruce pine (Pinus glabra). The type is widely distributed within the alluvial flood plains of the major rivers, occurring on all ridges in the terraces, and on the best, most mature, fine sandy loam soils on the highest first bottom ridges. It extends on first bottom ridges to a few well drained soils other than sandy loam. The site is seldom covered with standing water and rarely, if ever, overflowed although it may be hummocky and wet between the hummocks (10). The type becomes predominantly white oak on the most matured terrace soils. In very limited situations it is found with loblolly pine on terraces, and with spruce pine on terraces and on ridges in the first bottoms of small streams of the Coastal Plain east of the Mississippi River. It is found with yellow-poplar and beech only in the second bottoms of small secondary streams (10).

Among noncommercial trees or plant associates of cherrybark oak are red buckeye (Aesculus pavia), devils walking stick (Aralia spinosa), American hornbeam (Carpinus caroliniana), eastern redbud (Cercis canadensis), flowering dogwood (Cornus florida), witch hazel (Hamamelis virginiana), American holly (Ilex opaca), red mulberry (Morus rubra), southern bayberry (Myrica cerifera) and Carolina basswood (Tilia caroliniana) (5). In some localities such as the Delta region, pawpaw (Asimina triloba) and eastern hophornbeam (Ostrya virginiana) are also associates.

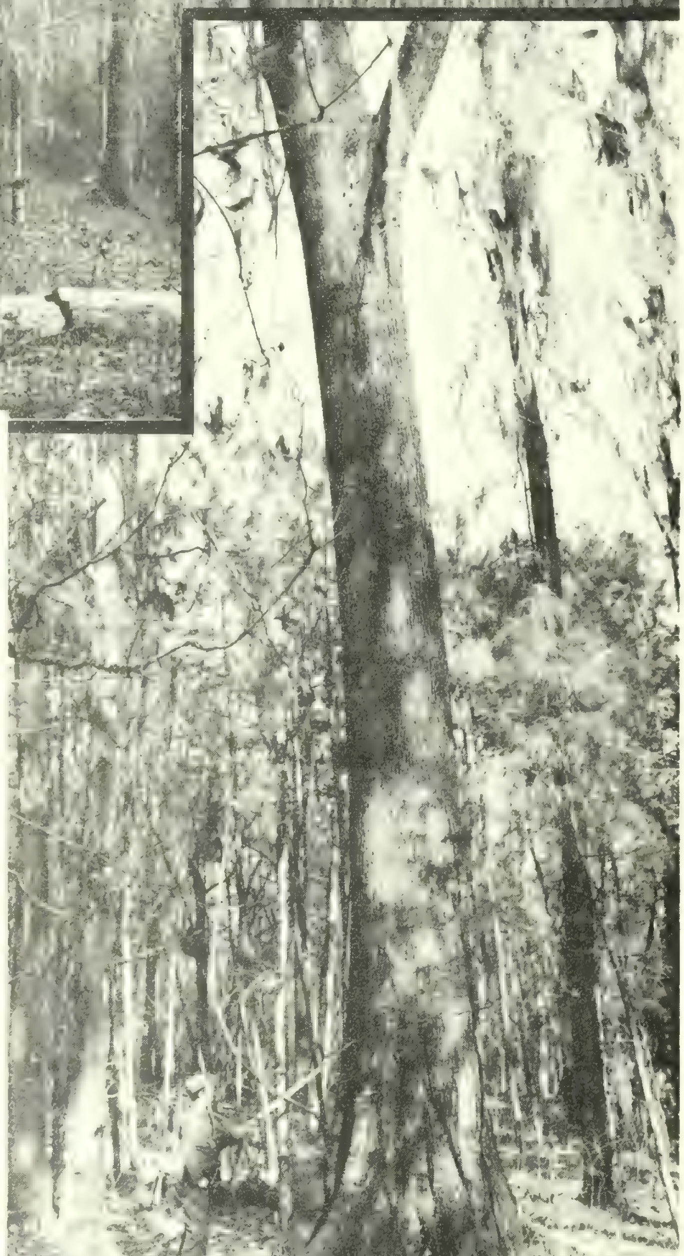
LIFE HISTORY

SEEDING HABITS

Flowering and Fruiting

The tree's flowers are unisexual, appearing with the leaves in March and April. The stamens are in hairy catkins 3 to 5 inches long, and the pistils solitary or in few-flowered spikes borne on short, stout hairy stalks (3).

A group of veneer-quality cherrybark oak from 24 to 30 inches d.b.h. growing on a second-bottom site adjoining a small stream in Berkeley County, South Carolina.



fine specimen of cherry bark oak 56 nches d.b.h. and 120 feet tall, growng in the Santee Experimental Forest, ear Charleston, South Carolina. This ree is about 70 years old.

The acorn fruit is solitary or in pairs; the nut is hemispherical or nearly globular, $\frac{1}{2}$ inch long, averaging about 750 per pound, often striate, orange brown; the cup is thin, saucer-shaped or sometimes toplike, and encloses about a third of the nut (3, 13). Ripening from September to November of the second year, the seed falls during this period (13). As in most of the oaks, the acorn is subject to damage by nut or acorn weevils such as *Curculio baculi*, *Curculio longidens*, *Curculio pardalis*, and *Conotrachelus posticatus*, and the filbert worm (*Melissopus latiferreanus*) (1). Acorn collections at the Santee Experimental Forest in South Carolina showed that insect-damaged acorns are readily distinguished from sound ones by the color of the cup scar: good acorns have a light, almost lemon color, while the bad acorns are a dull brown.

The domestic hog, which ranges in large numbers over the bottomlands of the South, probably consumes a major part of the annual crop of cherrybark oak acorns. Within the botanical range of this oak, certain other animals and birds include acorns as a substantial part (10 percent or more) of their diets (7). Among these the heaviest eaters are the gray squirrel (*Sciurus carolinensis*), wild turkey (*Meleagris gallopavo*), and the blue jay (*Cyanocitta cristata*), followed by the wood duck (*Aix sponsa*), red-bellied woodpecker (*Centurus carolinus*), red-headed woodpecker (*Melanerpes erythrocephalus*), white-breasted nuthatch (*Sitta carolinensis*), common grackle (*Quiscalus quiscula*), racoon (*Procyon lotor*), white-tailed deer (*Odocoileus virginianus*), and the eastern fox squirrel (*Sciurus niger*) (7). Because crops are frequent and the acorns are small in size, there is reason to assume that cherrybark oak acorns form a proportionate share of the total acorn diet.

Seed Production and Dissemination

Seed bearing probably follows the same pattern as southern red oak, beginning when trees are about 25 years old and attaining optimum production between 50 and 75 years of age. Good crops are frequent, occurring at 1 or 2 year intervals, with light crops in intervening years (13). A freeze in April, 1955, after the flower buds opened, resulted in a complete crop failure over much of the tree's range in 1956. Dissemination largely depends on hoarding activity of animals, especially squirrels. In certain situations (first bottoms) dissemination by flooding is possible. Gravity is a minor means of dissemination on the steeper terrace margins.

VEGETATIVE PROPAGATION

The tree is reported to sprout fairly efficiently from the stump when the shoot has been killed or cut back (8). However, this sprouting is not considered a dependable means for obtaining desirable natural regeneration. Like most oaks, this species is considered difficult to propagate by cuttings.

SEEDLING DEVELOPMENT

Establishment

Cherrybark oak regenerates naturally on areas protected from fire and grazing. Being an intolerant species, it requires full light for development (8). It often reaches its best development in old fields on well-drained loamy soils (9).

One test indicated that cherrybark oak acorns have an average germinative capacity of about 38 percent, which may be too low in view of the fact that two tests with southern red oak showed a high germination capacity of 91 percent (13). Typically, the seed remains dormant, germinating in the spring following seedfall.

The propagation of cherrybark oak by seeding or planting, like that of many hardwoods, has not been adequately explored. Studies in progress at the Santee Experimental Forest show third-year survival of 82 percent for planted 1-0 nursery stock, and 30 percent for direct seeded acorns on sandy loam soils associated with the first and second bottoms of small streams in Coastal South Carolina. It is understood that similar results have been obtained in the Mississippi Delta.

Early Growth

Indicative of early seedling growth of natural regeneration is the average total height of 20 inches attained in 3 years in the direct seeding tests. Sowings in the open were best, with an average height of 23 inches compared with only 17 inches under a forest cover.

As is common to most bottomland hardwoods, the sunlight necessary for seedling growth induces heavy competition from annual weeds, vines, briars, and brush, and this in turn may retard the early development of cherrybark oak unless released by weeding.

Insects known to attack and destroy reproduction of southern red oak, such as the hickory spiral borer (*Agrilus arcuatus* var. *torquatus*) and the oak borer (*Aneflomorpha subpubescens*) (1), probably affect cherrybark oak also.

SAPLING STAGE TO MATURITY

Growth and Yield

Cherrybark oaks often attain heights and diameters of 100 to 130 feet and 3 to 5 feet respectively, which classes them with the largest of the southern red oaks (3). It is one of the hardiest and fastest-growing of the oaks, or even of hardwoods in general, and grows well on a wider variety of sites than any other bottomland oak except willow and water oaks (9). Diameter growth will average from 3 to 6 inches in 10 years (8). In the

absence of extensive pure natural stands of cherrybark oak, area-wise volume and yield values are not available for the species. In mixtures with other hardwoods, under present-day forest conditions, a total volume in excess of 8,000 board-feet per acre for all species is classed as a heavy sawtimber stand; a heavy pole stand is one which exceeds 175 stems per acre of all species ranging from 5 to 11 inches d.b.h. (8). In the virgin forest, mixed stands ranged up to 30,000 board-feet per acre.

A good stand of cherrybark oak seedlings at beginning of fourth growing season since sowing of acorns. Spacing 4 x 4 feet on second bottom soil associated with a small stream in Coastal South Carolina.

Reaction to Competition

After release from suppression or if injured, the tree is apt to produce small adventitious limbs which result in many pin knots. But this is usually not too serious, and the grade yield of the species is generally high.

Principal Enemies

Fire is its chief enemy but fire damage is usually no more severe than in other species. Borers often cause much damage in badly fire-scarred veterans and in overmature timber. On poor sites, as on poorly drained clay flats, the mature trees are often infested with borers or mineral streaked. On these and other sites, fires and hurricane winds seem instrumental in introducing the borers and mineral streaks (9).

Insects identified as attacking southern red oak and probably also attacking cherrybark oak are: the orange-striped oak worm (Anisota senatoria) and the spiny oakworm (Anisota stigma), both defoliators; the two-lined chestnut borer (Agrilus bilineatus), Columbian timber-beetle (Corthylus columbianus), and pecan carpenter worm (Cossula magnifica), all wood borers (1).

Rot fungi attacking southern red oak and possibly cherrybark oak are Hydnum erinaceous, Polyporus hispidus, Polyporus sulfureus, and Daedalea quarcina (4). Leaf blister caused by Taphrina coerulescens is common.

SPECIAL FEATURES

Cherrybark oak is readily distinguishable from southern red oak by its more uniform 6- to 11-lobed leaves and its gray-black flaky or scaly bark which superficially resembles that of large black cherry (Prunus serotina) (11). The wood of cherrybark ranks high in texture and working qualities. It is usually firm to hard but straight-grained and workable even at its hardest. Its color is uniformly light red or a pink shade comparable to that of northern red oaks (9). Lumber is used to a great extent for high-grade products such as face veneer and factory lumber as well as for general utility.

RACES AND HYBRIDS

There are no known races or hybrids of cherrybark oak. However, cherrybark is a variety of southern red oak, which has a number of hybrids.

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Silvical Characteristics of Yellow-Poplar

by

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SILVICAL CHARACTERISTICS OF YELLOW-POPLAR
(*Liriodendron tulipifera* L.)

by

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Yellow-poplar (*Liriodendron tulipifera* L.) is also commonly known as tulip poplar, tuliptree, white-poplar, whitewood, and "poplar" (35). It gets its name from the tulip-like flowers which it bears in the late spring. Because of the excellent form and rapid growth rate of the tree, plus the fine working qualities of the wood, yellow-poplar is one of the most important hardwood species in the United States.

Yellow-poplar is found throughout the eastern United States from southern New England west to Michigan and south to Florida and Louisiana (19). It is most abundant and reaches its largest size in the valley of the lower Ohio basin and on the slopes of the mountains of North Carolina, Tennessee (47), Kentucky, and West Virginia.

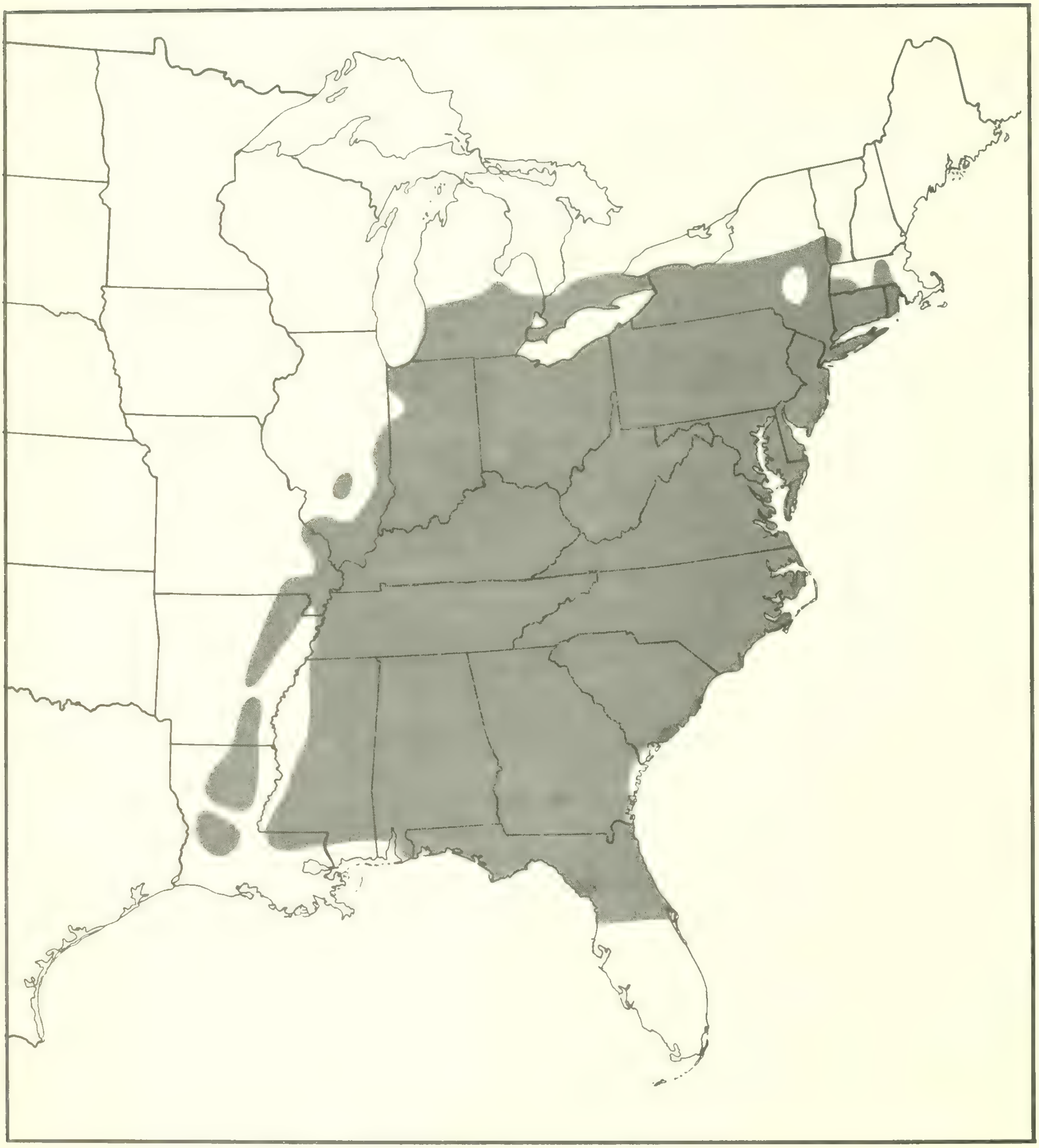
HABITAT CONDITIONS

CLIMATIC

Because of its wide occurrence, yellow-poplar grows within a broad range of climatic conditions. Temperature extremes vary from the moderately severe winters of southern New England to almost frost-free central Florida. Similarly, the range of rainfall varies within the territory from 30 inches to more than 80 inches for restricted areas in the Southern Appalachians (54). Its optimum development occurs where rainfall is well distributed over a long growing season. In a study in West Virginia, it was found that adequate rainfall early in the growing season had more effect on diameter growth than total rainfall during the entire season (53).

EDAPHIC

For good growth and form, yellow-poplar is quite exacting in its soil and moisture requirements. Where it occurs naturally, the sites are almost always moderately moist, well drained soils of loose texture, and it rarely grows well in very dry or very wet situations (38).



Botanical range of yellow-poplar.

In the Central States, Auten (2, 3) found that depth of A_1 horizon and depth to a tight subsoil were directly correlated with site index; in general, the presence of a tight subsoil less than 24 inches below the surface indicated a less than average site. Auten's relationship of height, age, and depth of A_1 horizon is:

$$\text{Height (in feet)} = 1.125 \text{ (age in years)} + 2.62 \text{ (depth of } A_1 \text{ horizon in inches)} + 23.06$$

In the Piedmont of North Carolina, the site indices of yellow-poplar and loblolly pine are similar on good sites. On lower slopes and alluvial soils the site index of yellow-poplar can be predicted by Coile's (13) loblolly pine equation for lower slopes; depth of A horizon and imbibitional water value of the B horizon are the important soil factors in this equation: 1/

$$\text{Site index} = 110.11 - \frac{101.0}{\text{depth of A horizon}} - 1.98 \text{ (imbibitional water value)}$$

Another study of yellow-poplar and loblolly pine in the North Carolina Piedmont also showed that there was no difference between the site indices of the two species on good sites and that on sites where yellow-poplar is found, depth of A horizon alone gives an approximate estimate of site quality: 2/

$$\text{Site index} = 74.88 + 0.7163 \text{ (depth of A horizon)}$$

Within the range of soils which he studied, Auten (3) found no correlation of site quality with calcium, magnesium, phosphorous, potassium, or with soil reaction (pH). Although the content of nitrogen in the soil varied from one area to another, it was not always consistent in its relation to site.

However, it is a well known fact that certain species of trees improve the fertility of the soil. A good example of this is shown by the effect of black locust on soil nitrogen and on the growth rates of associated species in 25-year-old forest plantations in Ohio and Indiana (11). Yellow-poplar planted close to black locust grew best; it definitely showed decreasing height and diameter growth with increasing distance from the locust. The soil under the yellow-poplar also showed a decrease in nitrogen with increasing distance from the locust.

PHYSIOGRAPHIC

At the northern end of its range, where low temperatures are a limiting factor, yellow-poplar is usually found in valleys and stream bottoms and at elevations below 1,000 feet. In the Appalachian Mountains, yellow-poplar

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1/ Metz, Louis J. Site indices of yellow-poplar and redgum on alluvial soils in the vicinity of Durham, N. C. 31 pp., 1947. (Unpublished M. F. thesis, School of Forestry, Duke Univ., Durham, N. C.)

2/ Hocker, Harold W. Jr., Relative growth and development of loblolly pine and yellow-poplar on a series of soil sites in the lower Piedmont of North Carolina. 40 pp., 1953. (Unpublished M. F. thesis, School of Forestry, N. C. State College, Raleigh, N. C.)

is at its optimum, and it grows on a wide variety of sites including stream bottoms, coves, and on slopes which have suitable moisture conditions--up to a maximum elevation of 4,500 feet in the Southern Appalachians. Toward the southern limit of the range, where high temperatures and soil moisture probably become limiting factors, the species is usually confined to well drained stream bottoms.

Aspect, position on slope (2, 40), and elevation are important topographic factors having an influence on the site quality for yellow-poplar.

BIOTIC

Yellow-poplar is a component of 16 of the 106 cover types listed for North America (50). It is the major species in 4 of these types, which are characterized by: (1) pure yellow-poplar; (2) yellow-poplar and hemlock; (3) yellow-poplar, white oak, and northern red oak; and (4) sweetgum and yellow-poplar.

On bottomlands and the better drained soils of the Coastal Plains yellow-poplar occurs in mixture with the gums, baldcypress (Taxodium distichum), the oaks (Quercus sp.), red maple (Acer rubrum), and sometimes loblolly pine (Pinus taeda).

In the Piedmont, associated species include the oaks, sweetgum (Liquidambar styraciflua), blackgum (Nyssa sylvatica), red maple, American elm (Ulmus americana), loblolly pine, shortleaf pine (Pinus echinata), and hickories (Carya sp.).

At the lower elevations in the Appalachian Mountains, it is found with black locust (Robinia pseudoacacia), white oak (Quercus alba), white pine (Pinus strobus), eastern hemlock (Tsuga canadensis), and black walnut (Juglans nigra), along with minor components of the hickories, other oaks, and yellow pines, together with flowering dogwood (Cornus florida), sweet birch (Betula lenta), blackgum, basswood (Tilia sp.), and silverbell (Halesia carolina). At the higher elevations associated species include northern red oak (Quercus rubra), white ash (Fraxinus americana), black cherry (Prunus serotina), cucumber tree (Magnolia acuminata), buckeye (Aesculus sp.), American beech (Fagus grandifolia), sugar maple (Acer saccharum), and yellow birch (Betula alleghaniensis). Species associated with yellow-poplar in nonmountainous areas of the North and Midwest include white oak, black oak (Quercus velutina), northern red oak, ash, beech, sugar maple, blackgum dogwood, and the hickories.

The twigs and branches of yellow-poplar are tender and tasty to livestock and white-tailed deer (Odocoileus virginianus), and young trees are often heavily browsed. Seedlings are grazed to the ground, small saplings are trimmed back, and even large saplings may be ridden down and severely damaged. On areas where animals are concentrated, young yellow-poplar is frequently wiped out. Rabbits also eat the bark and buds of seedlings and saplings, and can be quite destructive at times.

Other animals seek out the seed of yellow-poplar. Some of these animals are: quail (Colinus virginiana), purple finch (Carpodacus purpureus), cardinal (Cardinalis cardinalis), cotton-tail rabbit (Sylvilagus floridanus), red squirrel (Sciurus hudsonicus), gray squirrel (Sciurus carolinensis), and the white footed mouse (Peromyscus sp.) (37, 56).

LIFE HISTORY

SEEDING HABITS

Flowering and Fruiting

Yellow-poplar flowers from April to June (55), depending on geographic location and the weather. The flower of yellow-poplar is tulip-like in form and size, and is one of the favorite sources of nectar for honey bees. In fact, it has been suggested that the percentage of sound seed is directly related to the number of honey bees visiting the flowers.

The fruit is a cone-like aggregate of many winged carpels or samaras borne on a central spike. About 80 winged carpels are produced in each fruit (9), and each carpel bears two seeds, one usually aborted. Fruits begin to mature in late September.

Seed Production

Although yellow-poplar is a prolific seeder, few seeds per strobile are fertile--the rest are empty seed coats. Germination tests of stratified seed showed a low of 1 percent, a high of 14 percent, and an average of 5 percent (55).

Bumper crops of seed occur only at irregular intervals, but studies at Duke University show that a seedfall of 300 thousand or more seeds per acre is not uncommon (9). Cutting tests in this study gave an average of 11.1 percent of sound seeds for a 3-year period; however, cutting tests usually show a much higher viability of seed than germination tests. Trees with larger diameters produce both a greater number of cones and a greater number of sound seeds than trees of smaller diameter. For example, at Duke a 10-inch tree produced about 750 cones and 7,500 sound seeds, but a 20-inch tree produced 3,250 cones and 29,000 sound seeds.

The minimum seed-bearing age is 15 to 20 years, and the maximum age is undetermined, but it is known to be more than 200 years. In Indiana, trees 15 inches and less in diameter yielded as high a proportion of filled or good seed (on a per-tree basis) as larger trees, and sometimes higher; seed from the upper two-thirds of the crown was better filled than seed from the lower third (18). Also, trees in closed stands did not have a higher proportion of filled seed than trees in open stands, and site or soil fertility was not a factor within the limits of this study in determining quality of the seed harvested.

Wean and Guard (60) have determined that trees in Indiana vary widely in the production of viable seed, and that a given tree is consistent through the years in the production of a given viability. A low producer will be consistently low, and a high producer will be consistently high over the years.

Carpenter and Guard (8) found that cross pollination of yellow-poplar in Indiana increased the percent of filled seed per cone up to as high as 90 percent, where the highest for open-pollinated seed was 34.8 percent. At the end of 4 months after germination, seedlings from the cross-pollinated seed were taller than seedlings from the open-pollinated seed, and the largest seedling from a cross had about twice the height of the largest seedling from open-pollinated seed. This study indicates that by planting together seedlings from widely separated seed parents, seed will be produced which will give both improved germinative capacity and more vigorous seedlings.

Seed Dissemination

As they dry in the cone, the individual winged seeds are scattered by the wind to distances equal to four or five times the height of the trees (38). At Duke University (9), seedfall began in early October and reached a peak in early November. Sound seed was disseminated from mid-October to mid-March; seed falling early and late had about the same percentage of soundness.

Seed dissemination is generally high during warm, dry weather and low during cool, wet weather.

VEGETATIVE REPRODUCTION

Several investigators have tried to root yellow-poplar cuttings, but no results have been satisfactory (4, 25).

Although yellow-poplar sprouts readily and vigorously from stumps and rootstocks, and frequently grows and develops satisfactorily in clumps, sprout stands are not as desirable as stands from seed. Trees of sprout origin are not only more apt to develop heart rot than are seedlings, but sprouts often grow from small stumps which rot quickly, leaving little support against ice and wind damage. Sprouts from small stumps and rootstocks or seedling sprouts do have tremendous vigor and can usually outgrow the sprouts of any other competing species, as well as seedlings of the same species.

McCarthy (38) regards the sprouting ability of yellow-poplar as a safeguard in case young seedlings are destroyed by fire, or as a last resort where clearcutting for pulpwood in young stands has left little or no seed. It is recognized today that many young new stands have developed from sprout origin, and this recognition is important, because of the extra need for cultural attention during the early years.

SEEDLING DEVELOPMENT

Establishment

The successful regeneration of yellow-poplar calls for adequate seed, a seedbed of mineral soil, adequate soil moisture, sufficient direct sunlight for early growth, and some shelter for the seedlings by a light cover of grasses, shrubs, and trees (9, 38).

Eight to ten seed trees (14 to 20 inches in d.b.h.) per acre are considered necessary for the regeneration of cutover land in the Piedmont of North Carolina (9). However, as often happens in the mountains, one large seed tree favored by topography and prevailing winds may seed in an area of several acres (17). If logging is done during the fall or winter, and seed trees are not considered necessary for insurance, seed from the trees removed in cutting may be sufficient to regenerate cutover areas.

While an area is being cut and logged, proper seedbed and light conditions can usually be provided. It is important that the forest floor is scarified, and if this is not accomplished during logging or if logging is not done during the dormant season, it may be necessary to employ additional means of scarification. Seed that does not immediately reach mineral soil may remain dormant for a year or perhaps longer (38).

Sims (49) points out that burning following clear cutting may be desirable for preparing a seedbed. Although burning may be a good idea on areas with a heavy accumulation of raw humus, regeneration can usually be accomplished without burning.

After germination, several critical years follow. During this period sufficient soil moisture must be available; good drainage and protection against drying and frost heaving are necessary, and there must be no severe competition from nearby sprout growth.

The method of cutting yellow-poplar to get regeneration can be quite flexible. Several methods have been successfully used in the past, including clearcutting, seed tree cutting, and group selection. The important criteria of a good cutting method are that it must not only leave an adequate seed source and a mineral seedbed, but the surrounding cutover area must be large enough to allow for growth of the new crop.

Yellow-poplar can be planted successfully, provided sufficient care is exercised in selecting the site and in the planting itself. Yellow-poplar should not be planted on dry, exposed, old-field sites (38, 41, 48) because the few seedlings that survive make poor growth.

Minckler (40, 42, 43) found that north and east exposures should be favored for planting yellow-poplar, and steep south slopes should be avoided in the Appalachian Valley of Tennessee. The planting site should not be eroded, and there should be at least 12 inches of topsoil present. The site

should be moist but well drained, preferably with a light to moderate cover of vegetation. Minckler also lists other factors affecting plantation success as follows: soil type, first year precipitation, permeability and porosity of the soil, and rodent activity.

In addition to advising against planting on dry old-fields in Michigan, Shipman and Rudolph (48) recommend planting on borders or in small openings to provide side shading and protection against sun-scald damage.

At the end of 5 years, records of planted yellow-poplar in northern Mississippi show that release is necessary to attain satisfactory survival and height growth on lower slopes and bottomlands--the two sites where this species does best (62).

Excellent height growth of planted yellow-poplar has been attained in the Central States by planting in mixture with black locust on old fields (12) and by underplanting in 8- and 9-year-old black locust plantations on strip-mined land (15).

A recent study of preplanting treatments in Ohio (39) showed that in old fields yellow-poplar seedlings made the greatest height growth when planted on the "lay" or overlap of a double furrow.

Yellow-poplar plantings in the Central States show the importance of grading seedlings and improving nursery techniques (33, 34). In southeastern Ohio (34), the heights of 5-year-old seedlings originally graded to a 6/20-inch stem diameter (1 inch above ground line) were 1 foot taller than seedlings that had been graded to 3/20 inch. Seedlings 15 inches high at time of planting were 1 foot taller than seedlings that had been 5 inches high at time of planting. A combination of root pruning and grading of seedlings improved survival even more (33).

In the Southern Appalachians (29), planting yellow-poplar proved to be much more reliable than direct seeding in spots. After 4 years, only 40 percent of the seed spots had seedlings surviving, while 95 percent of the planted seedlings were living. Seedlings on seed spots averaged only 0.10 foot in height, as contrasted with 1.27 feet for planted seedlings.

Because of their carrot-shaped or wedge-shaped taproot, yellow-poplar seedlings are frequently lost to frost heaving, particularly those planted on clay.

Early Growth

On favorable sites the success of regeneration can usually be determined by the size and vigor of seedlings at the end of the third year. Height growth during the first year ranges from a few inches to more than a foot on the best sites. With full light, rapid height growth begins the second year, and at the end of 5 years heights may be 10 to 18 feet. McCarthy (38) cites one example of a yellow-poplar of seedling origin which was 50 feet in height at 11 years of

age. Yellow-poplar is inherently capable of making extremely rapid growth, especially during its seedling and sapling stages; rapid height growth is also assisted by the good sites on which it generally grows.

Toumey (52) describes the root system of yellow-poplar as having a rapidly growing and deeply penetrating juvenile taproot, as well as many strongly developed and wide-spreading lateral roots or sinkers. He states that root habits are inherent with a species and they are usually less flexible or adaptive to environment during the juvenile period than in later years. However, yellow-poplar is considered by Toumey to have a flexible rooting habit, even in the juvenile period.

The behavior and duration of height growth of yellow-poplar has been found to vary by latitude. In Pennsylvania (26) yellow-poplar seedlings had a 95-day height growth period beginning late in April and ending about August 1. A sharp peak in height growth was reached about June 1. In northwestern Connecticut (28) yellow-poplar had a 110-day height growth period beginning in late April and ending in mid-August. Ninety percent of its height was put on in a 60-day period from May 20 to July 20. A sharp peak in height growth was noted in the middle of June. In the lower Piedmont of North Carolina (32) yellow-poplar had a 160-day period of height growth, beginning in early April and ending about the middle of September. However, height growth was more constant throughout the growing season, and there was no peak in height growth at any time during the growing season.

In greenhouse studies it is often necessary to break dormancy of seedlings during the winter. Kramer (31) found he could break the dormancy of yellow-poplar by either exposing seedlings to low temperatures or treating the seedlings with ethylene chlorohydrin; and combination of the two treatments was even more effective in advancing the date for breaking dormancy.

Even though seedlings of yellow-poplar and many other hardwoods have no leaves in winter, they have been found to transpire during the winter at about the same rate, on the basis of unit area exposed, as conifers do (30).

SAPLING STAGE TO MATURITY

Growth and Yield

Mature yellow-poplar may reach 190 feet in height and 10 feet in diameter (24), but trees approaching this size are now rare. Good second-growth stands may attain heights of over 120 feet and diameters of 18 to 24 inches in 50 to 60 years. Probable yields for various ages and sites are shown in table 1, which was adapted from McCarthy (38).

Table 1.--Normal yield per acre for second-growth yellow-poplar 1/

Age (Years)	Basal area by site indices of-- 70	90	110	Volume 2/ by site indices of-- 70	90	110	Volume 3/ by site indices of-- 70	90	110
	--Square feet--.			--Cubic feet--			--Board-feet--		
10	--	8	17	--	50	250	--	--	200
20	39	60	75	600	1,180	1,765	650	2,000	5,180
30	70	97	116	1,305	2,300	3,320	2,650	8,710	15,600
40	97	128	150	2,010	3,390	4,800	6,780	16,300	27,350
50	122	157	183	2,705	4,480	6,220	11,400	24,400	40,200

1/ All trees 5 inches or more d.b.h.
2/ Peeled volume of merchantable stem to a 3-inch top diameter inside bark.
3/ International 1/8-inch rule. Stump height 1 foot; top diameter inside bark 6 inches.

Typical second-growth yellow-poplar stand 45 years of age. This stand occupies a bottom-land site which at one time was a cultivated field.

In a study in West Virginia, the average diameter growth of yellow-poplar for the last 10 years by diameter classes was as follows (21):

Present d.b.h. (Inches)	D.b.h. growth in last 10 years (Inches)
6	3.55
8	3.37
10	3.19
12	3.00
14	2.82
16	2.64
18	2.46
20	2.28
22	2.09
24	1.91

Vigor classes as used by Campbell (7), Burkle and Guttenberg (6), and Holcomb and Bickford (21) reflect not only size of crown, but also the general thrift of the tree. Vigor classes have been correlated with diameter growth and used in studies of economic maturity for yellow-poplar and other species. For example, in the Southern Appalachians, yellow-poplar reaches economic maturity for sawtimber at from 18 to 26 inches d.b.h., the exact size depending upon the vigor of the tree and the interest rate used (7). The following tabulation showing financial maturity for upland yellow-poplar in Alabama (6) illustrates the key role of vigor class and concomitant diameter growth.

Vigor (Class)	3-percent interest (D.b.h.)	4-percent interest (D.b.h.)
High	30-31	26-27
Medium	26-27	22-24
Low	21-22	19-21

Yellow-poplar plantations at about age 20 years often show mean annual growth rates of 1 to 1½ cords per acre, depending on site and density of stocking. A 17-year-old plantation on an excellent stream-bottom site in central Georgia carried a total basal area of 153 square feet and 30 cords of wood per acre (44).

Reaction to Competition

Being an intolerant species, yellow-poplar cannot withstand severe competition. It is able to overcome some competition simply because it grows so rapidly. In the Piedmont and mountains of the Southeast, yellow-poplar is extremely sensitive to site change; on the very best sites it showed the highest site index of any species of hardwoods or conifers studied, and on the poorest sites it showed the lowest site index (45, 51).

The place of yellow-poplar in succession, as a pure type, is temporary. It often comes in as a pioneer on abandoned or clearcut land where seed and soil moisture conditions are favorable, only to be in turn invaded by more tolerant species such as oaks, hickories, or northern hardwoods. Yellow-poplar even more often regenerates as a mixed type with other species, and it commonly persists in climax stands as scattered individuals.

Because of the intolerance of this species, cleaning young seedlings or saplings is an important part of its management. Dominant and codominant yellow-poplar seedlings or saplings do not respond well to cleaning, but good-vigor trees in overtopped and intermediate crown classes respond quite readily in terms of both greater height and diameter growth (16). In a study of cleaning yellow-poplar in the Southern Appalachians, Abell (1) and Wahlenberg (57) showed that the greatest benefit at 10 and 25 years

after cleaning, respectively, was in the increased number of desirable stems and a better species composition. The cleaning also resulted in an increased yield of 6 cords of wood at the 25-year mark.

Yellow-poplar prunes itself well except in very sparsely stocked stands. Therefore, artificial pruning will probably not be necessary unless yellow-poplar becomes a more important planted species and is grown on a short rotation at a wide spacing. In well stocked stands on good sites, individual tree growth may slow down about the twentieth year, and, unless the stands are thinned, crowding and the accompanying reduction in size of crown may continue until growth is seriously retarded.

In thinnings made at about 20 years of age the material will usually be large enough for pulpwood. A study in West Virginia (59) shows that moderate thinnings may be desirable at short intervals. This will keep the stand sufficiently closed so that epicormic branching will not be serious (58), nor will the danger from ice or glaze be as great as with heavier thinning (10).

Holsoe (22) states that desirable crown length of yellow-poplar can be maintained by repeated thinnings; 60-foot crown lengths are possible when trees reach 100 feet in height. He recommends moderate to heavy thinnings at 8- to 10-year intervals in which 30 to 40 percent of the volume is removed. Through such intensive management, it may be possible to obtain annual growth of nearly 1,000 board-feet per acre during the last half of the rotation. In the process, basal area growth will be increased, the rotation shortened, and the specific gravity and strength of the wood increased (23).

Principal Enemies

Yellow-poplar is considered to be unusually free from diseases. Though subject to various canker, stain, and decay fungi, it is seldom extensively damaged (5).

Discolorations of the wood are very common following any type of wounding, but these discolorations, except when associated with decay, do not affect strength of the wood.

Young yellow-poplar is susceptible to cankers caused by *Nectria magnoliae*, but these cankers soon heal over on dominant or codominant trees (27).

Although decay often follows top breakage (46) or butt wounds from fire (20), these decays may or may not become extensive, depending upon the size of the wound and the species of rot fungus. Most of the decay is caused by *Collybia velutipes*, *Pleurotus ostreatus*, *Hydnum erinaceus*, and *Polyporus versicolor*; in one study (38) *Armillaria mellea* was the most common rot affecting fire-damaged trees.

The common leaf spots caused by species of *Cercospora*, *Cylindrosporium*, *Gloeosporium*, *Phyllosticta*, and *Mycosphaerella* (61) do not result in excessive damage.

Sapstreak, a disease caused by the fungus Endoconidiophora virescens has been found killing an occasional tree. At present, this disease is very rare, and is known only in western North Carolina.

Yellow-poplar is also relatively free from insect damage, despite a few pests which attack the leaves, branches, and stem. The foliage is occasionally fed upon by larvae of miscellaneous butterflies and moths, and it is frequently attacked by the tulip gall fly (Thecodiplosis liriodendri), which causes purplish blister-galls to form on the leaves. The branches and twigs may be attacked by several species of scale insects, among the most important of which is the tulip tree scale (Toumeyella liriodendri). These attacks seldom affect the health of the tree seriously.

Borers may occasionally degrade lumber seriously by tunnelling in the sapwood or heartwood. Most important is the Columbian timber beetle (Corthylus columbianus), a very aggressive ambrosia beetle which enters the sapwood of living trees (14). The defect, known as "calico poplar," consists not only of black-stained burrows, but discoloration may extend in the wood for a foot or more both above and below the point of attack. Dying trees and logs may be injured by the sapwood timber worm (Hylecostus lugubris), and the heartwood beneath blazes and wounds is often riddled by the flatheaded sycamore borer (Chalcophora campestris).

Because of the extremely thin bark, yellow-poplar seedlings and saplings are extremely susceptible to fire damage (38), and even a light ground fire is usually fatal to stems up to an inch in diameter. On large trees, when the bark reaches a thickness of a half inch or more, good insulation is provided against all but the hottest fires. Even then an entry may be provided for heartrot which will subsequently cause a hollow-butted condition.

Sleet and glaze storms occurring periodically within most of the range of yellow-poplar can also cause considerable damage (10, 38). Slender trees may be broken off, and stump sprouts are particularly susceptible to injury. Dominant and codominant trees often suffer top breakage which, if severe enough, will reduce the growth rate. This top damage often causes the trees to be infected with top rotting fungi at the point of injury. Although this species usually makes remarkable recovery after such storms, repeated damage can result in a serious reduction in rate of growth and general quality of the tree. Other enemies of this species include the sapsucker (Sphyrapicus vaius), which causes considerable degrade in the lumber, grapevines (Vitus sp.), which reduce the growth and sometimes kill the trees, and Japanese honeysuckle (Lonicera japonica), which is particularly serious because it thrives on the best sites, smothering small yellow-poplar saplings and precluding regeneration.

Frost damage to young yellow-poplar in certain localities, and the retarding effect which frost, especially in frost pockets, can have on the early growth and development of the tree, may have been overlooked somewhat in the past.

SPECIAL FEATURES

It has been reported that a yellow-poplar tree of less than 20 years of age will yield about 8 pounds of nectar or about 4 pounds of honey per season (38). Thus, the income from a stand of yellow-poplar may be greatly enhanced by keeping bees in the stand. As mentioned earlier, the more bees in a stand, the better the chances will be for more complete pollination and consequently a higher percentage of filled seed.

RACES AND HYBRIDS

There are no known natural hybrids of yellow-poplar, but the possible existence of races and geographic strains is being studied (34, 36).

After the third growing season, seedlings of North Carolina Coastal Plain origin were almost twice as high as seedlings that originated in the mountains of North Carolina (36). These seedlings are growing together in the Coastal Plain near Charleston, South Carolina.

It appears that seed from southern latitudes may have a lower germinative capacity and may produce less frost-hardy plants than seed from northern latitudes.

Yellow-poplar seedlings show distinct racial variation in a study at the Santee Research Center. At left, the North Carolina mountain source is only 4.4 feet in height in its third growing season. At right, the North Carolina Coastal Plain source of the same age is 7.9 feet in height.

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Silvical Characteristics of Sweetgum

by

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Director

U. S. DEPARTMENT OF AGRICULTURE FOREST SERVICE

ıt the time these photos were
aken, this was the largest liv-
ng sweetgum known. Located
n the Big Pee Dee Swamp,
ear Florence, South Carolina,
t measured 21½ feet in circum-
erence, 82½ inches in diameter,
.nd 200 feet in height.

Cut because of hollowness
and decay in 1950 by the
owner, Vestal Lumber an(
Manufacturing Company,
the first 10-foot butt log
had to be left in the woods
Even so, the tree yielded
8,085 board-feet.

SILVICAL CHARACTERISTICS OF SWEETGUM
(*Liquidambar styraciflua* L.)

by
Donald L. Martindale
Formerly of the Southeastern Forest Experiment Station

Sweetgum (*Liquidambar styraciflua* L.), also known as American sweetgum, bilstead (23), red gum, sap gum, starleaf gum, gum (1), sycamore gum, gumwood, sweetgum, and alligator tree (42), is highly valued both as a forest tree and as a shade tree. Its botanical range is shown in figure 1; however, the species is also planted as a shade tree in California and the Pacific Northwest (45). It is found naturally in the mountainous regions of Mexico and in scattered locations as far south as Honduras and Nicaragua (2). Occasional occurrence of the species in the swamp forests of Massachusetts may be an indication of the northward trend in its range (2).

Red gum was formerly the accepted common name for the species, but this name, as well as *sap gum* and *gum*, is now restricted to sweetgum lumber. In the lumber trade, the term *sap gum* applies to sapwood, and *red gum* applies to heartwood. The species is much used for lumber as well as for veneer and plywood. In 1948, the manufacturers of boxes, crates, furniture, and cabinets accounted for more than 90 percent of the sweetgum used in the wood products industry. Sweetgum pulp is also used in the making of fine grades of paper, corrugated board, and rayon (1). It can be used for any paper product that will tolerate a mixed hardwood pulp.

HABITAT CONDITIONS

Climate

According to Thornthwaite's classification (39), sweetgum grows in the humid climate of the eastern United States. The effect of climate on the growth of sweetgum within its commercial range is greatly modified by annual or periodic floods and the high water tables associated with bottomland sites.

Annual rainfall varies from 40 inches in the North to 60 inches in the South, and the growing season rainfall is 20 and 34 inches, respectively. There are 180 frost-free days in the northern part of the range and 320 in the southern part. Mean January temperatures are less than 30° F. in the North and about 50° in the South; minimum temperatures during the year are -5° in the North and 25° in the South. Maximum temperature during the year is about 100° for most of the range of sweetgum (44).

Edaphic and Physiographic

Sweetgum is very tolerant of different soils and sites but attains its best development on the rich, moist, alluvial clay and loam soils of river bottoms (6).

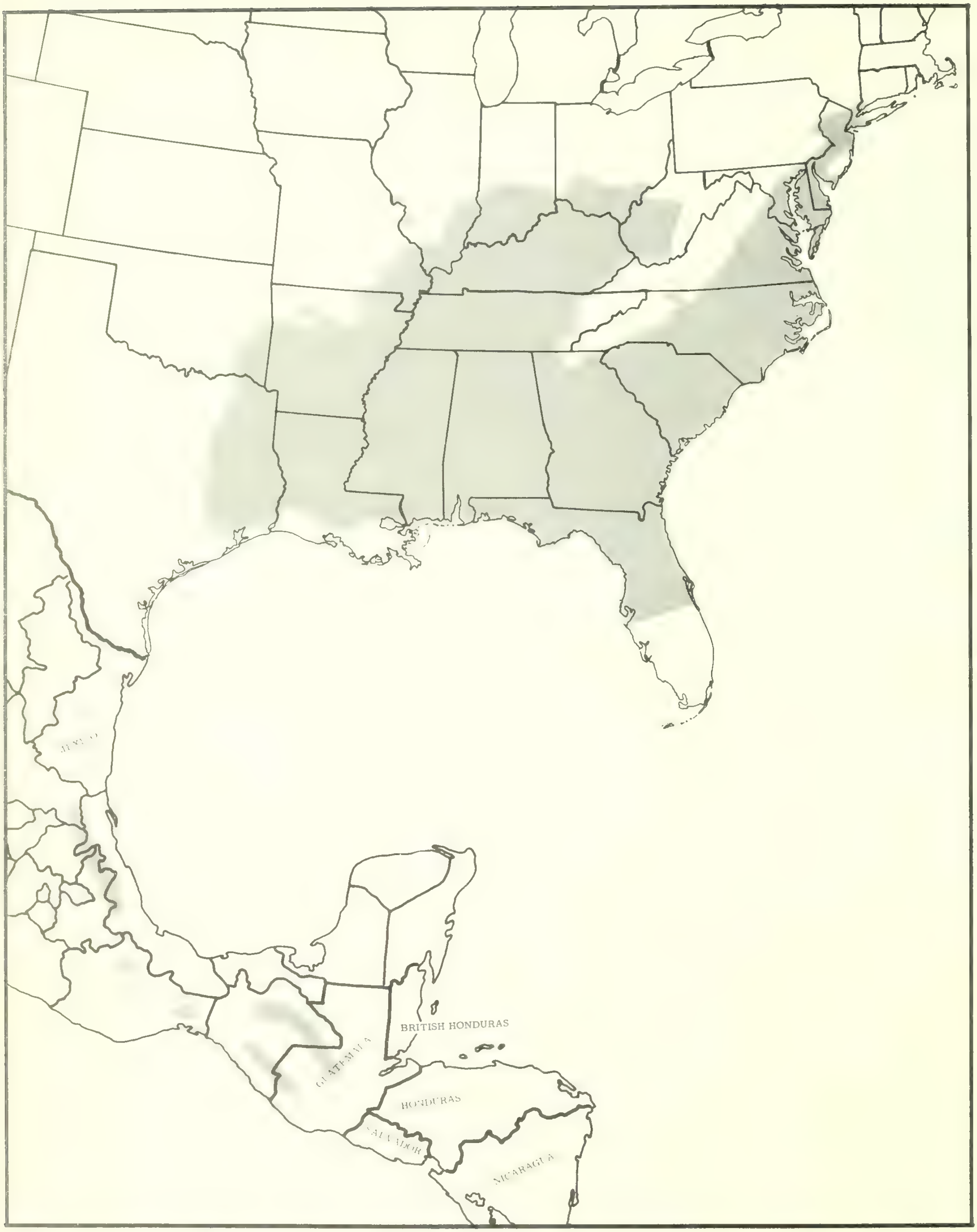

Figure 1.--Botanical range of sweetgum.

In Maryland, sweetgum is rarely found on well drained, sandy soils, usually being confined to heavy, moist soils. While it is common on clay or gravelly clay uplands, it grows poorly there. The best growth is restricted to alluvial swamps and to imperfectly and poorly drained soils having a high clay content (42).

Sweetgum is reported as an occasional dominant on the loessal soils along the east border of the Mississippi River alluvial plain. Dominant stands of sweetgum are often found on the relatively impervious planasols of the Illinoian till plain--including the very poorly drained Avonburg, Blanchester, and Clermont silt loams (2, 5).

Turner (43) related the occurrence of forest cover types (37) to topography and soil type in Arkansas. The cover types in which sweetgum is a major component were found primarily on the alluvial clay and loam soils of the river bottoms. The cover types in which sweetgum is listed as an associated species decrease in number with increasing elevation and are confined to loam soils.

On north slopes in the Ozark Mountains, sweetgum is a minor component of the stand and does not exert dominance; here it is always associated with soils derived from chert (34).

In the surcharge zone of reservoirs on the lower Tennessee River, sweetgum plantations attained their best growth on moist silty and sandy loams having a loose, deep surface soil and a permeable subsoil. The poorest growth was associated with sites having poorly drained, compact subsoils (36).

Height growth of 3-year-old sweetgum plantations in the Appalachian Valley varied from 0.41 to 0.60 foot per year on soils of dolomitic and limestone origin, respectively (28). In the same plantations, survival and growth of sweetgum was affected by soil type, soil profile, depth of A horizon, and consistency of A and B horizons. In general, the best sites for sweetgum were found to be those suitable for yellow-poplar (Liriodendron tulipifera), but sweetgum is not so demanding in site as yellow-poplar (29).

In the bottomlands, Braun (2) reports that sweetgum attains its best growth on low ridges. However, Chittenden (6) found growth slower on the ridges than in the glades of the Mississippi bottomlands. In the Mississippi Delta the species is most common "on silty clay or silty clay loam ridges and very moist but not too poorly drained silty clay flats in first bottoms" (33).

Except for the higher elevations in the Appalachians, there are apparently no altitudinal limitations on the occurrence of sweetgum in the eastern United States. In Mexico the species is found primarily at elevations that range from 3,500 to 6,500 feet, but its best development is on deep soils at elevations of 4,000 to 5,300 feet (30).

Biotic

In eastern North America, sweetgum is a predominant species in four forest cover types and an associated species in 24 additional ones. Of the cover types in which sweetgum is present, eight are found in the central forest region, while the rest are indigenous to the southern forest region. Considering all these cover types in both regions, we find five types on dry sites, three types on wet sites, and the remainder on fresh to moist sites (38).

Because of its wide distribution, adaptability to a variety of sites, and inconsistency in time of appearance in natural succession, there is considerable variation in the plant and animal associates of sweetgum. Over 65 tree species (2, 6, 31) and 30 shrub species (31) are associated with sweetgum. The principal tree species with which sweetgum is associated as a predominant species are shown in table 1 for four forest cover types.

Table 1.--Predominant and associated species of forest cover types in which sweetgum is an integral member (38)

Type	Predominant species	Associated species
Northern red oak-mockernut hickory-sweetgum	Northern red oak (*Quercus rubra*) Mockernut hickory (*Carya tomentosa*) Sweetgum	White oak (*Quercus alba*) White ash (*Fraxinus americana*) Blue ash (*Fraxinus quadrangulata*) Slippery elm (*Ulmus rubra*) September elm (*Ulmus serotina*) American elm (*Ulmus americana*) Blackgum (*Nyssa sylvatica*) American sycamore (*Platanus occidentalis*) Red maple (*Acer rubrum*) Silver maple (*Acer saccharinum*) Sugar maple (*Acer saccharum*) Black walnut (*Juglans nigra*) Honey locust (*Gleditsia triacanthos*) Black cherry (*Prunus serotina*)
Pin oak-sweetgum	Pin oak (*Quercus palustris*) Sweetgum	Red maple Elms (*Ulmus* spp.) Hickories (*Carya* spp.) Swamp white oak (*Quercus bicolor*) Bur oak (*Quercus macrocarpa*) Ash (*Fraxinus* spp.) River birch (*Betula nigra*) Hackberry (*Celtis occidentalis*)
Sweetgum-yellow-poplar	Sweetgum Yellow-poplar	Loblolly pine (*Pinus taeda*) Red maple White ash Green ash (*Fraxinus pennsylvanica*)
Sweetgum-Nuttall oak-willow oak	Sweetgum Nuttall oak (*Quercus nuttallii*) Willow oak (*Quercus phellos*) Water oak (*Quercus nigra*)	Sugarberry (*Celtis laevigata*) Green ash American elm Overcup oak (*Quercus lyrata*) Pecan (*Carya illinoensis*) Water hickory (*Carya aquatica*) Cedar elm (*Ulmus crassifolia*) Eastern cottonwood (*Populus deltoides*) Laurel oak (*Quercus laurifolia*) Red maple Honey locust Common persimmon (*Diospyros virginiana*)

Despite the wide range and abundance of sweetgum, it is utilized only to a small degree by wildlife. Ten species of birds and three species of mammals are reported as eating the seeds, bark, or wood. The eastern goldfinch (Spinus tristis) is the only bird that depends upon sweetgum seed for an appreciable part of its winter food. The seed also forms a small part of the fall diet of the eastern gray squirrel (Sciurus carolinensis). The bark and wood furnish 10 to 25 percent of the food for beaver (Castor canadensis) in the Southeast (25).

LIFE HISTORY

Seeding Habits

Flowering and fruiting.--Flower buds of sweetgum are extremely sensitive to cold, and they are often damaged by frost (42); the flowers appear from March to May, depending on latitude and weather. In the fall, the fruit turns yellow, and the seeds mature from September to November. Soon after maturity, the seed is disseminated by the wind, but the empty fruits often remain on the tree for the entire winter (45).

Seed production.--Seed production, which begins when the tree is 20 to 30 years old, remains abundant until about age 150. Fair seed crops are produced each year, with bumper crops every two or three years (42, 46).

Full sunlight and rich soil are conducive to optimum seed production, and under such conditions each fruit may average as high as 50 sound seed (42). However, under average conditions only 7 or 8 sound seeds are produced by each fruit, and 1 bushel of fruit will yield 12 ounces or approximately 60,000 seeds (46).

Seed dissemination.--The maximum recorded distance of seed dispersal is 600 feet, but ordinarily 96 percent of the seed lands within 200 feet of the point of release (14).

Vegetative Reproduction

Sweetgum is capable of sprouting until it is approximately 50 years of age (6). The season of cutting has no effect on the number of sprouts, but, for a given diameter of stump, the shortest sprouts develop on stumps of trees cut in May and August. No decline in sprout vigor occurs until the third generation following the cutting of successive generations of sprouts from the same stump (49).

Seedlings of sweetgum reach a height of 4.5 feet in 3 to 5 years, but sprouts often reach this height in 1 growing season. Duration of this rapid growth is unknown but 10-year-old sprouts frequently have the same size and appearance as 18- to 20-year-old seedlings in the same stand. The presence of "twins" in a 99-year-old stand would indicate that sweetgum sprouts are capable of developing into sawtimber (51).

Guttenberg (14) and Kaufert (20) have concluded that many of the old-field stands of sweetgum are of sprout origin. Many of these sprouts originate as root sprouts from cut trees.

The literature records no successful attempts at reproducing the species vegetatively by cuttings or aerial layers.

Seedling Development

Establishment.--Mineral soil is an ideal seedbed, but sod is not a serious hinderance to seed germination. When additional sweetgum reproduction is desired in partially cutover stands, exposed mineral soil and abundant direct sunlight are usually necessary. Lack of direct sunlight is probably the most limiting factor in the development of pure sweetgum stands on cutover timber land (42). Guttenberg (14) recommends that seed trees be spaced approximately 100 feet apart to assure adequate distribution of seed.

Sufficient moisture is especially important following germination, until the taproot of the seedling begins to develop (42). With watering conditions similar, potted seedlings of sweetgum were found to have a higher mortality in sandy soil than in clay or silt loam (48).

Early growth.--Root development varies with the site. A deep taproot and numerous horizontal rootlets usually develop early. However, in wet areas the root system is shallow and wide-spreading, with little or no taproot. On gravelly ridges and hillsides, sweetgum develops a particularly strong taproot and is very wind resistant (42).

Few measurements of early growth are available. Trenk (42) reports 5-year-old seedlings averaging 8.7 feet in height on an abandoned field adjacent to a swamp in Maryland. Seedlings in a Maryland nursery averaged 10 inches in height at the end of one growing season. On favorable sites in the lower Mississippi Valley, seedlings grow as much as 2 feet during the first year, both in the nursery and in the field.

Several sweetgum plantations have been established in the surcharge zones of reservoirs on the lower Tennessee River. Plantations in one reservoir were flooded with 2 to 4 feet of water from April through June with no apparent damage to the seedlings. Height growth of plantations on bottomland loam soils varied from 5.2 to 6.9 feet for a 5-year period. On upland sites the 5-year height growth of the plantations varied with the ground cover at time of planting (36):

Ground cover	Height growth (Feet)
Surface soil removed	3.6
Broomsedge and goldenrod	5.1
Areas reverting to woody cover	6.5

Sweetgum is a highly desirable species for planting on relatively acid strip-mine spoil banks in the Central States (11). The average height of 7-year-old sweetgum planted in pure stands was nearly 7 feet on a strip mine area in Indiana; in the same plantation, sweetgum planted in mixture with black locust and other hardwoods averaged over 10 feet in height.[1/]

In the Georgia Piedmont, sweetgum begins its radial growth 20 to 30 days after full leaf development, or about the third week in May. Fifty percent of the annual radial growth is completed within 40 to 49 days after radial growth (19) commences.

Sapling Stage to Maturity

Growth and yield.--Young sweetgums have long conical crowns that usually prune readily under forest conditions (6). The branches of young trees are at an acute angle to the stem (42). Mature trees have crowns that are round and spreading to ovate in shape, while the tops of overmature trees are usually broken or stag-headed (6). The species responds slowly to release, except while young, i.e., below 10 inches d.b.h. (33).

Maximum sizes attained by sweetgum in different parts of the country are:

Location	Height (Feet)	Diameter (Inches)
California (46)	50	--
Pacific Northwest (46)	80-120	--
Northeast (46)	50-75	--
Mississippi River bottom (6)	150	60
Maryland, well-drained uplands (42)	65	18-25
Maryland, river bottom (42)	110	36-42
Coastal Plain, swamp (9)	120	48

Because of the tree's tendency to fork at a definite stage in its development, the maximum length of clear stem for sweetgum in South Carolina was 58 feet. In South Carolina, forking occurred when the trees were approximately 16 inches d.b.h. In Missouri the maximum length of clear stem was 57 feet, but because of a lower growth rate, forking did not occur until the trees were much older and larger in d.b.h. than those in South Carolina (6). In Maryland, crowded stands of sweetgum virtually cease height growth at 65 to 70 years of age, at which time the crowns tend to flatten (42).

Sweetgum in a selectively logged, virgin "red gum ridge-oak" type in central Louisiana grew 1.57 inches in diameter during the 8 years prior to cutting. In the 8 years following cutting, diameter growth averaged 1.86 inches (8).

1/ Denuyl, Daniel, Tarbox, G. L., and Funk, David T. Growth of sweetgum planted on Indiana coal mine spoil banks. 1956. (Unpublished manuscript on file with the Department of Forestry, Purdue University, Lafayette, Indiana.)

Bull (4) reported the 10-year average diameter growth for overmature sweetgum as 1.9 inches. He concluded that the average growth for immature trees was probably 2.5 to 3.0 inches over a 10-year period. Vigorous sweetgum trees have a thick bark with distinct high ridges, while those of low vigor are characterized by a flatter and thinner bark. Ten-year diameter growth rates by vigor class are (15):

Vigor (Class)	Diameter growth (Inches)
High	3-4
Medium	2-3
Low	1-2

Forest resource data for the north Louisiana Delta showed the following growth rates for various diameter classes of sweetgum (50):

Diameter class (Inches)	Ten-year diameter growth (Inches)
6-12	2.12
14-18	2.18
20-28	2.02
30+	1.49

In the Mississippi Delta, pure stands of sweetgum average 6,000 to 8,000 board-feet per acre. Very good stands will have 15,000 to 20,000 board-feet per acre, with 30,000 to 40,000 on small selected areas. Ridges usually have lighter stands than the flats. In virgin stands of mixed bottomland hardwoods, sweetgum averages 5,000 to 6,000 board-feet per acre (33).

In the lower Piedmont of North Carolina, loblolly pine had 187 percent greater board-foot volume than sweetgum, when compared on a tree basis on all sites. There was no over-all difference in the site index curves of the two species. However, the site index of sweetgum was higher than the site index of loblolly pine on the bottomlands, while the reverse was true for all other sites.[2/]

Reaction to competition.--Winters and Osborne (51) point out that in pure stands on bottomland sites:

> "The young red gum tree is able to endure a certain amount of shade and stand crowding; hence the leaf and crown canopy of young stands is usually dense. With increased age, however, the trees become less able to endure competition. The most suppressed red gum trees die from crowding and the stands become more open. Following the natural decrease in the density of the crown canopy, sufficient sunlight reaches the ground to permit the development of an understory stand. . . . This understory is present in nearly all even-aged, second-growth, red gum stands more than 40 years old."

2/ Ralston, James. The relative productivity of loblolly pine and sweetgum on forest sites in the lower Piedmont of North Carolina. 40 pp. 1955. (Unpublished M.F. thesis, N.C. State College, Raleigh, N. C.)

Sweetgum is classified as intolerant by Zon and Graves (53). Their tolerance scales were modified by Toumey and Korstian (41), who classified sweetgum as intermediate in tolerance. Chittenden (6), who classified the species as intolerant, pointed out that it is nearly always a dominant or intermediate tree, and that seldom is an overtopped sweetgum found in the forest. Perhaps a better tolerance classification would be intermediate as a seedling or sapling, and intolerant in the larger sizes.

On poorly drained upland soils (Illinoian till plain) of southern Indiana, sweetgum, pin oak, and red maple are the principal species coming in first on old fields. These are followed next in succession by increased numbers of sugar maple, yellow-poplar, shagbark hickory, and black cherry. And finally a composition resembling the original old growth forest is developed by the prominence of beech, pin oak, and sweetgum along with white oak, black walnut, yellow-poplar, black cherry, and sugar maple (5).

In pure, upland southern pine stands of all ages, sweetgum seedlings or sprouts are usually present. The species is present as an understory tree in all but the youngest pine stands and only occasionally as a dominant tree in the older stands (31). Removal of the pine overstory results in rapid growth of the sweetgum (42). Sweetgum forms a small part of the total hardwood component of the pine stands; in the climax oak-hickory forest, it is also a very minor constituent (31).

The successional pattern of pure bottomland pine stands is similar to the upland pine stands, except that the rate of succession is considerably faster in bottomland stands, and sweetgum is represented by a greater number of stems in the pine overstory (31).

Speaking of bottomland hardwood succession, Oosting (31) says:

> "Red gum is recorded in every stand but its density as well as percent of total density vary widely and inconsistently. Ages of individuals within a stand have a wide range, and the time of appearance in the stand likewise varies considerably. All this should probably be expected, for red gum may be found in a great variety of habitats and conditions. In the bottoms it may appear as a pioneer tree, alone or with other species. Thereafter it maintains itself in competition and continues to reproduce for a surprising number of years....Of the species appearing early in bottomland succession it is least sensitive to environmental differences and best adapted to successful growth and competition under a variety of conditions. In spite of irregularities....it is unquestionably the most important pioneer tree in the establishment of the mixed hardwoods in bottomlands."

Principal enemies.--Fall frosts often kill the late summer shoot growth of sweetgum (42). Seedlings may be badly damaged by hogs, goats (6), or cattle. Rodents, particularly mice and rabbits, are reported to have caused considerable damage to young seedlings in sweetgum plantations in various localities (10, 22, 27, 36). In southern Illinois, rabbit injury varied from 9 percent on graded spoil banks to 82 percent on ungraded spoil banks at the end of 3 years (10).

Young sweetgum plantations in the Appalachian Valley of eastern Tennessee made good growth on the better sites, but field mice are so fond of this species and kill so many seedlings that its use in planting seems inadvisable except on good sites in rodent-free areas (27).

Sweetgum is very resistant to disease and insect attack, but it is highly susceptible to death or injury by fire. Summer fires damage understory sweetgum more than winter fires, as shown by a study of prescribed, annual burns in loblolly pine stands of the South Carolina coastal plain. One year after the third summer fire, 33 percent of the sweetgums were dead (24).

Fire scars on living trees may furnish entrance points for insects and fungi (6), although quite frequently basal wounds become covered with a gum exudation which prevents the entrance of fungi and insects. As long as the sapwood is not killed by fire, this protective layer of gum will form over it. However, with repeated fires, a tree is more apt to have some sapwood killed, and fungi and insects may become established. For example, in the lower delta of the Mississippi River, 42 percent of the sweetgum trees burned one time showed decay 8 years later; and 79 percent of the sweetgum trees burned repeatedly during an 8-year period showed decay (17).

The upward rate of the spread of decay in young fire-scarred sweetgum is approximately 1.2 inches per year in the Mississippi River Delta. A characteristic of this decay is that it is usually confined to the cylinder of wood extant at the time of scarring. In the same locale the rate of healing for fire-scarred sweetgums having a firm surface to heal over was 0.56 inch per year (17).

Kaufert (20) estimated that 90 to 95 percent of the decay in bottomland hardwoods was due to fire and that very little cull was due to fungi entering branch stubs or wounds on the upper stems. He also reported that 12 percent of the merchantable volume of a virgin sweetgum stand in Louisiana was left in the woods because of rot. Lentz (21) estimated that a tract of virgin sweetgum in the Mississippi Delta was deteriorating at the rate of one percent or more each year.

A check list of the fungus enemies of sweetgum includes many that are of secondary importance (47). The four most common decay organisms in the Mississippi River Delta are *Fomes geotropus*, *Pleurotus ostreatus*, *Lentinus tigrinus*, and *Polyporus lucidus* (17). Some relatively new and possibly serious diseases of sweetgum have been reported: bleeding necrosis of sweetgum (32), leader die-back or blight (12), and sweetgum blight (26). None of the causal agents for these diseases has been positively identified. Sweetgum blight is widely distributed (18), and has caused heavy mortality in several states. It has received intensive study in Maryland (52) and Mississippi (40), and may be related to soil properties affecting moisture supply (3).

Except for the leaf feeders, the insect enemies of sweetgum are capable of attacking only lumber or trees that are damaged, dead, or decadent. Of these insects the ones capable of attacking living tissue are the bark beetles,

which include *Dryocoetes betulae*, *Dryocoetes liquidambarus*, and *Pityophthorus liquidambarus*; the ambrosia beetles, which include the flatfooted ambrosia beetle (*Platypus compositus*) and the darkling beetles (*Strongylium terminatum* and *Strongylium tenuiolle*); and the leaf feeders, which include the forest tent caterpillar (*Malacosoma disstria*) and the luna moth (*Tropaea luna*) (7, 35).

SPECIAL FEATURES

Sweetgum is often characterized by corky, wing-like protrusions of bark on opposite sides of the twigs and branchlets. Between and within individuals, the amount of "winging" varies inconsistently and sometimes develops into a bark wartiness that persists for several years. Usually the protrusions fall off after the second or third year leaving a smooth branchlet (42).

Most sweetgum trees, especially those of low vigor, develop epicormic branches at some time during their development, but thinning stands lightly will help to prevent excessive epicormic branching (42). Harrar (16) found dormant and adventitious buds a major defect in sweetgum veneer logs.

The crushed leaves and twigs of sweetgum have a distinctly sweet and aromatic odor (42). When wounded or injured, sweetgum produces a gum called storax. A pathological product formed in the living wood and exuding from intercellular spaces (13), this gum commonly fills the cells adjacent to wounded areas and forms a dense, hard layer over the face of scars (17). Sweetgums are occasionally tapped for the commercial production of storax, which is used in adhesives, salves, incense, and perfume (1).

RACES AND HYBRIDS

Information on the races of sweetgum is lacking, and although another species, *Liquidambar orientalis*, is native to western Asia, no hybrids of sweetgum are known to exist.

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Silvical Characteristics of Pond Pine

by

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Silvical Characteristics of Pond Pine

(Pinus serotina Michx.)

by
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Pond pine (Pinus serotina Michx.) is found in the Coastal Plain from southeastern Virginia south to central and southeastern Alabama, and on Cape May, New Jersey (fig. 1) (11). It occurs more frequently in poorly drained flats than on drier uplands, and is the characteristic tree of the extensive evergreen-shrub bogs, commonly called "pocosins," in eastern North Carolina.

HABITAT CONDITIONS

CLIMATIC

The climate of the pond pine range is mild and humid. The frost-free season ranges from 190 days in the north to 347 days in the south (19). Rainfall averages 45 to 55 inches annually, but exceeds 60 inches in western Florida. It is heavier in the summer, nearly twice as much rain falling from June to August as in any other 3-month period. Average maximum temperatures are 90° to 100° F. and average minimum temperatures are 10° to 20° F. Temperatures of -10° in the north and 110° F. in the south have been recorded.

PHYSIOGRAPHIC AND EDAPHIC

The lower Coastal Plain is very flat and characterized by swamps, marshes, and poorly developed drainage patterns. In North Carolina the interstream areas are very broad and poor drainage has resulted in development of extensive beds of peat and organic soils (21). These areas are true upland bogs, with streams draining them on all sides. For that reason they were given the name "pocosin," or "swamp-on-a-hill," by the Indians, and are so called to this day. Here the largest acreages of pure pond pine stands occur. Farther south, shallow, poorly drained depressions, called bays or ponds, frequently support stands of pond pine. On better drained soils, pure stands are not common, and the species is usually found as an associate in other forest types.

Although pure stands occur most frequently on soils of high organic matter content, the species grows best on mineral soils.[1] Height growth is slower as the organic matter content of the soil increases. Peat beds are the poorest sites for pond pine and the site index becomes lower as the depth of the peat increases.

1/ Hoffman, J. G. The effect of certain soil characteristics on the height growth and site index of pond pine in the Coastal Plain of the Carolinas, Georgia and Florida. 1949. (Doctorate dissertation, Duke University.)

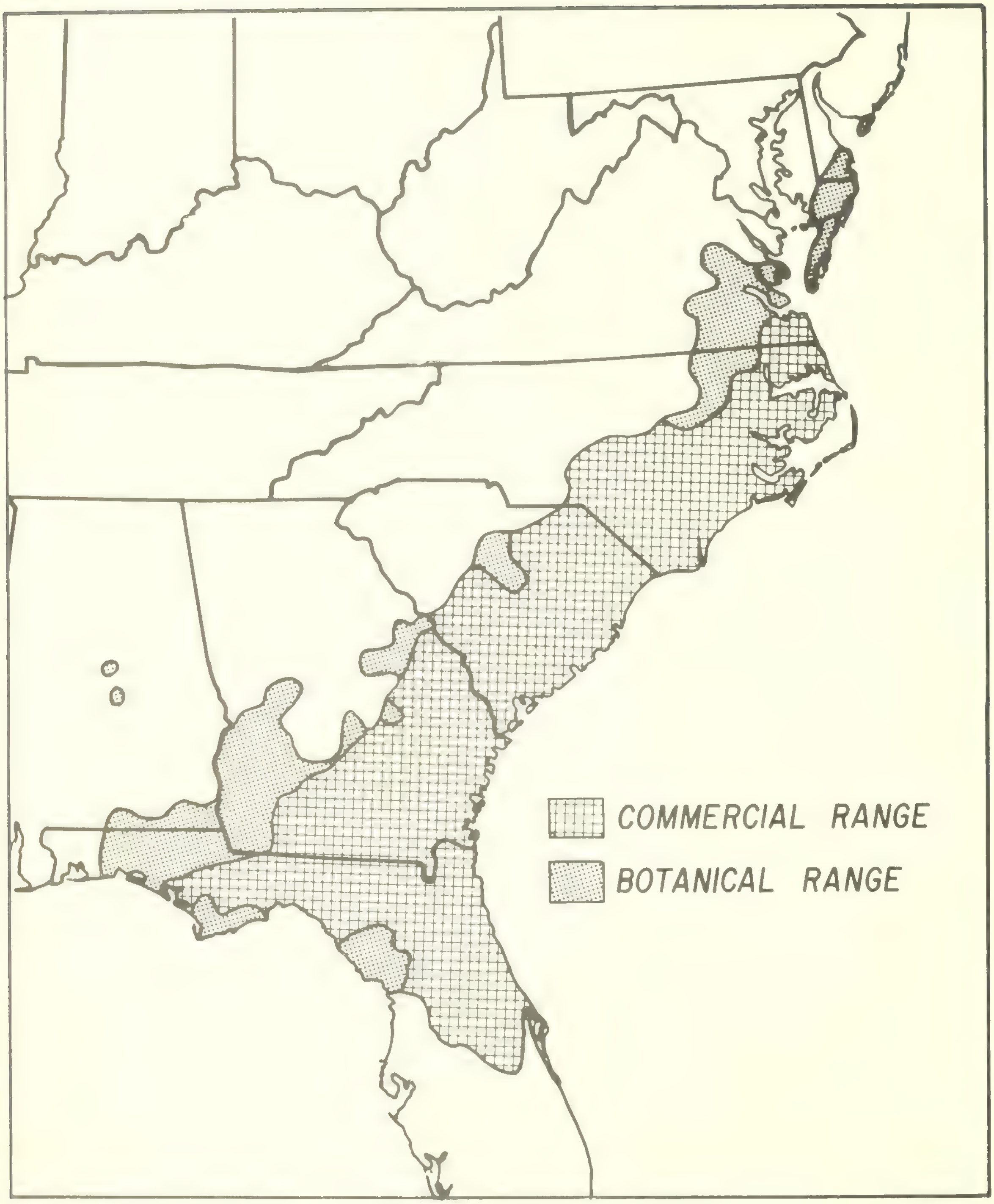

Figure 1.--The botanical and commercial range of pond pine.

The slower growth on organic soils results mainly from prolonged water saturation, which prevents soil aeration.[2] Poor aeration retards decay of organic material and causes high soil acidity. Although availability of mineral nutrients is usually adequate, nitrogen fixation and nitrification proceed very slowly. Consequently, the amount of available nitrogen is small, even though total nitrogen content is high in the undecayed organic matter. Soil saturation also deprives roots of the oxygen required for respiration and growth and tends to keep soil temperature low.

BIOTIC

Minor associates in pure stands of pond pine are loblolly pine (Pinus taeda), baldcypress (Taxodium distichum), sweetgum (Liquidambar styraciflua), sweetbay (Magnolia virginiana), loblolly-bay (Gordonia lasianthus), redbay (Persea borbonia), and swamp tupelo (Nyssa sylvatica var. biflora) (16). In the pocosins, or evergreen-shrub bogs, trees are usually rather scattered and a great variety of evergreen shrubs form a dense understory (21). Common shrubs are gallberry (Ilex glabra), tall inkberry (Ilex coriacea), zenobia (Zenobia cassinefolia), swamp ironwood (Cyrilla racemiflora), waxmyrtle (Myrica cerifera), bayberry (Myrica caroliniensis), and saw palmetto (Serenoa repens). Laurel greenbrier (Smilax laurifolia) is almost always present and switch cane (Arundinaria tecta) is locally abundant.

On moist or wet sites, pond pine is the chief associate in the cabbage palmetto-slash pine type, the Atlantic white-cedar type, and the pondcypress type (16). It is also frequently found in the loblolly pine, slash pine, slash pine-hardwood, slash pine-swamp tupelo, and sweetbay-swamp tupelo-red maple types on poorly drained sites.

While no animal can be said to be directly associated with pond pine, the black bear (Euarctos americanus) is fairly common in the extensive pocosins where pond pine is the characteristic tree. With the exception of several large swamps, the black bear is practically nonexistent in other parts of the Coastal Plain. Other animals native to the region are also found more or less abundantly in pond pine areas.

LIFE HISTORY OF THE SPECIES

SEEDING HABITS

Flowering and Fruiting

Flower buds are formed some time during the summer, and flowers bloom late the following March in Florida and about a month later in North

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[2] Auten, J. T. Soil site reconnaissance of Dare County, North Carolina. West Virginia Pulp and Paper Co., N. C. Woodlands Res.--Westvaco Expt. Forest Rpt. NO-1. 1955. (Cited by permission of the West Virginia Pulp and Paper Co.)

Carolina (2). Pond pine normally flowers considerably later than loblolly or slash pine in the same latitude, but the flowering period may overlap that of loblolly pine in some years.

Cones require two growing seasons to mature. They ripen early in September in eastern North Carolina (6) and probably a few weeks earlier in the southern part of the range.

Seed Production and Dissemination

Pond pine begins to produce cones at an early age. In a pocosin area in eastern North Carolina, 4- to 10-year-old trees produced a total of 8 cones per tree over a 3-year period (6). Cone production increased rapidly up to 40 years of age, then remained constant. At less than 40 years of age, cone production was directly related to both age and diameter. At greater ages, it was directly related only to diameter.

In the same study, the percentage of defective cones was strongly related to tree age, ranging from 8 percent on trees less than 10 years old up to 61 percent on trees over 60 years old. Most of the loss was probably caused by a small moth, Dioryctria amatella. Trees older than 30 years bore an average of 170 sound cones.

The cones of pond pine are serotinous and few open to release seed the same autumn they ripen. Consequently, cones of several ages are normally present on cone-bearing trees (fig. 2). They open gradually over several

Figure 2.--Closed, sound cones of several ages on one branch.

years. Scarcely any closed, sound cones older than 5 years were found in eastern North Carolina (6), but frequent fire may have caused many cones to open early. Cones open more readily on some trees than on others. Open cones may persist 10 years or longer on the trees. The cones open rapidly following surface fires or felling of the trees. In bright sunlight on summer days, cones begin to open a few minutes after the tree is felled, but in the shade or during the cooler hours, or in winter, they open more slowly (6).

The total number of seeds per cone averaged 79 and was found to be directly related to length of the cone, but did not vary significantly with age or size of the tree. In the study in eastern North Carolina, 23 percent of the seeds were not released during extraction treatment, suggesting that all seeds are not released when the cones open on the tree. The viability of extractable seed averaged 48 percent and varied significantly among individual trees and tree ages. Viability did not vary with the length of time sound cones remained on the trees, however. Seed from 3-year-old cones germinated as well as seed from 1-year-old cones.

The intense heat and partial burning to which cones are subjected during fire apparently do not seriously reduce the viability of the contained seed. Fifty-nine percent of seed from cones that were badly charred during a fire in eastern North Carolina germinated within 30 days after planting, while seed from slightly charred cones was 57 percent viable.[3/]

Pond pine seed is wind-disseminated. It is smaller than loblolly pine seed, averaging 54,000 per pound (20). Consequently, it probably is distributed at least as far from the source as loblolly pine seed. However, because the cones open gradually over a period of several years, no specific period of seedfall exists. Seedfall probably occurs at any season of the year if the weather is warm and dry. In eastern North Carolina, appreciable quantities of seed began to fall in April and continued to fall until November, but the viability was only 30 percent, in comparison with 60 percent for seed falling immediately after a fire.[4/]

VEGETATIVE REPRODUCTION

Unlike most other pines, pond pine sprouts readily to advanced ages. Seedlings sprout prolifically, and stands up to sapling size are re-established by sprouting after light fires. Older trees also sprout and put forth many sprouts along stems and branches after defoliation by fire or other agencies (fig. 3).

3/ Ernst, William, Jr. Official correspondence, Southeastern Forest Experiment Station, Asheville, N. C. March 12, 1957. (Used by permission of the West Virginia Pulp and Paper Company.)

4/ Crutchfield, D. M. Official correspondence, Southeastern Forest Experiment Station, Asheville, N. C. December 10, 1957. (Used by permission of the West Virginia Pulp and Paper Company.)

Figure 3.--Pond pine on land of West Virginia Pulp and Paper Company, Dare County, North Carolina. Above, stem and branch sprouts after severe fire. Left, stem sprouts on fire-defoliated tree.

Sprouts arise from dormant buds that are formed in the axils of primary needles of young seedlings (17, 18). The buds remain alive and are protected by bark and the characteristic crook at the base of most seedlings, but they do not sprout unless the seedling is injured. These buds may give rise to secondary buds, forming clusters of dormant buds embedded in the bark just above the root collar.

In addition, not all buds formed at intermediate and winter nodes sprout the following spring. Those that do not sprout remain alive, sometimes developing into short, weak branches and so give rise to many lateral buds. They may also put forth secondary dormant buds directly without growing into branches. Buds may also form in needle fascicles but these are of little importance in the sprouting of pond pine because they are present only a short time (12). Thus, pond pine stems and branches bear many clusters of dormant buds that remain alive and capable of sprouting for many years. When trees are defoliated by fire, these buds sprout and give the stems and branches a feathery appearance. Stem sprouting is one of the primary reasons for the low quality of pond pine in frequently burned areas.

SEEDLING DEVELOPMENT

Establishment

Although specific data on the seedbed requirements of pond pine are not available, exposed mineral soil is probably the best seedbed. However, adequate moisture for germination evidently is also present in peat and organic soils because of the high water table, and pond pine seed germinates readily on exposed surfaces. Thus, in two different locations in eastern North Carolina, very few seedlings were established in the absence of fire, but satisfactory numbers appeared following burning (15).[5/]

The number of seedlings established varied with intensity of burning. After a head fire, 58,200 seedlings per acre were found, compared with 25,500 after a flank fire. This difference was due to better seedbed conditions created by the headfire rather than to seed supply. In another area 2,250 seedlings per acre became established after an intense wildfire, but only one-sixth as many followed a comparatively light fire. Seed supply apparently was an important factor in this case.

In one burned area, seedling numbers decreased with increasing depth to water table. Four times as many seedlings followed burning in brush as in switch cane areas, but seedling numbers did not vary significantly with brush density. Because brush and switch cane areas were in different locations, factors other than cover type may have influenced seedling establishment.

5/ Besse, J. D. Initial influence of fire on the regeneration of pond pine. 1952. (Master's thesis, School of Forestry, North Carolina State College.)

Other activities that expose mineral soil, such as logging or grazing, have been ineffective in promoting seedling establishment. These failures were apparently due to lack of seed, since logging and grazing do not hasten opening of the cones on trees of the seed source. In Dare County, North Carolina, exploratory trials of prescribed burning for site preparation resulted in satisfactory stocking of seedlings, but comparatively few seedlings were established where site preparation consisted only of disturbance incidental to logging, or of disking, brush cutting, or fire plow furrowing after logging.[6/]

The favorable seedbed conditions created by burning deteriorate in a few years. In one test, 1,700 seedlings per acre were established in the first growing season after burning and 500 per acre in the second. Some of this difference was probably due to seed supply, since most seed is probably cast soon after the fire.

The mortality of seedlings is greatest in their first year and declines in subsequent years. In a pocosin area in eastern North Carolina, seedling mortality was as follows (15):

Seedling height class (Inches)	Mortality per year (Percent)
1-6	30
7-12	19
13-24	11
25-72	3

In a similar area, 20 to 25 percent of seedlings in brush died during the second year.[7/] In switchcane, seedling mortality varied with the intensity of the preceding fire; 38 percent died where a headfire had burned, and 17 percent died where the burning had been by a flank fire.

Because pond pine cones do not open readily unless heated, natural regeneration is extremely slow and very uncertain in the absence of fire. A properly timed and executed fire will bring down a large quantity of seed and prepare the seedbed at the same time. Burning may be done either before or after the harvest cut, but a prelogging fire will result in the fall of a larger amount of seed and will also improve logging conditions. However, satisfactory techniques for prescribed burning in pocosin areas have not yet been developed. Because organic soils will burn when dry, burning should be done only when the water level is near the surface of the ground, but with such conditions the vegetation often will not burn. On the other hand, when the vegetation is dry enough to carry the fire, the rate and intensity of burning may be so great that the fire gets out of control.

6/ See footnote 4.

7/ See footnote 3.

Lopping and scattering cone-bearing slash after mechanical scarification of the seedbed may also be effective, but saturated organic soils often will not support heavy equipment.

Seed trees will be needed if fire follows logging and probably should also be left when fire precedes logging. Trees 9 to 10 inches d.b.h. and larger and 30 years or more in age can be expected to produce at least 5,000 sound seed each (6). Thus, at least 6 trees per acre are needed for the satisfactory seeding of a prepared seedbed.

Early Growth

On mineral soils the beginning of shoot growth in spring probably occurs at about the same time that it does in loblolly pine. On organic soils, it is closely related to the drop in the water table that occurs when temperature rises and transpiration increases (15). However, organic soils hold large amounts of water and warm up slowly, so that growth of pond pine begins later than on mineral soils (9).

In a study of pond pine seedling growth in a pocosin area in eastern North Carolina (15), seedlings grew more in height in their first year than in any of the next 2 or 3 years. These seedlings also grew more in years of lesser rainfall, probably because the water level dropped earlier and the growing season was therefore longer. The data indicated that the average seedling would become 5 feet tall in about 18 years and the fastest growing seedlings would reach that height in less than 10 years. Another group of seedlings became 5 feet tall in 8 to 10 years (4). Growth rates of pond pine seedlings from 1943 to 1946 in a peat area were as follows (15):

Height class (Inches)	Average annual growth (Inches)	Maximum annual growth (Inches)
1-6	1.9	13.0
7-12	1.5	9.1
13-24	3.3	17.0
25-36	4.8	15.2
37-48	6.8	18.0
49-60	8.0	17.2

Although pond pine characteristically grows in poorly drained areas, pond pine seedlings suffered more than loblolly pine seedlings from prolonged flooding of the root system in greenhouse experiments. One test showed that 3 months of continuous flooding permanently injured the roots of pond pine, but loblolly pine was permanently injured only by flooding for 10 months (5). Another test showed that pond pine seedlings could endure

flooding only two-thirds as long as loblolly pine. [8] The deep root systems and wind-firmness of pond pine trees in the presence of high water tables suggests that older trees may be able to tolerate flooding better than seedlings.

The photosynthetic rate of pond pine is undoubtedly lower than that of associated hardwoods. The needles are arranged just as in loblolly pine, in which the lower photosynthetic rate is caused by mutual shading of the needles (10). Consequently, pond pine seedlings are at a disadvantage in competition with hardwoods and will probably respond to release in the same way as other southern pines (8). In eastern North Carolina, pond pine seedlings grew slightly faster in a grazed area, probably because grazing reduced competition (15).

The Nantucket pine moth (*Rhyacionia frustrana*) is regularly found attacking pond pine seedlings and small trees. On poor sites, attacks by this insect may seriously reduce height growth. Other insects which may occasionally cause serious losses are the pales weevil (*Hylobius pales*), sawflies (*Neodiprion* spp.), and the pine webworm (*Tetralopha robustella*).

SAPLING STAGE TO MATURITY

Growth and Yield

The height growth of pond pine is faster on soils of heavier texture and good internal drainage, indicated by greater depth to mottling. [9] Pond pine also grows faster in the southern part of the range, where the growing season is longer. In pond pine areas, surface soil contains varying percentages of organic matter, and height growth is slower where the organic matter content is higher and the organic layer deeper.

Pond pine normally does not grow to large size in pocosins and its growth is retarded by frequent fires. Average sizes attained in a pocosin in North Carolina were as follows (7):

Age (Years)	Height (Feet)	D.b.h. (Inches)
20	28	5.8
50	49	10.4
100	66	13.8

8/ Gaiser, R. N. The growth of loblolly and pond pine seedlings under differing conditions of soil flooding. 1947. (Unpublished manuscript, Dept. of Botany, Duke University.)

9/ See footnote 1.

On sites of better quality, which occur on mineral soils and the margins of pocosin areas, growth rates are considerably higher. On beds of deep peat, growth is very slow.

Stands in pocosins have rather low volumes, seldom over 5,000 board-feet per acre. The trees are often of poor form and quality. Although well-stocked stands may be found on poor sites, stand density generally increases with site quality,[10/] and on favorable sites where fires are infrequent, stands of greater volume and of good vigor and form occur. Site quality in pocosins can often be substantially improved by drainage, which also improves logging conditions.

Yields of pond pine stands at 55 years range from 6 standard cords per acre on 40-foot sites to 45 cords per acre on 90-foot sites.[11/]

Pond pine is subject to the fusiform rust (Cronartium fusiform) and the round gall rust (Cronartium cerebrum), both of which cause stem and branch lesions and have alternate stages on oak. Several rusts (Coleosporium spp.) attack the foliage but have little effect. Pond pine needles are sometimes severely browned by Hypoderma lethale and by the brown-spot fungus (Scirrhia acicola), but severe damage is rare. Red-heart (Fomes pini) is common in some stands, especially on poor sites, and may greatly reduce their value.

Pond pine is also subject to attack by the southern pine beetle (Dendroctonus frontalis), the black turpentine beetle (Dendroctonus terebrans) and the engraver beetles (Ips spp.).

Reaction to Competition

Although the tolerance of pond pine has not been judged, it should probably be considered an intolerant tree, of about the same degree of tolerance as loblolly pine, less tolerant than slash, and more tolerant than longleaf. Thus, pond pine should respond to thinning in much the same way as other intolerant species.

On mineral soils, pond pine is a transient stage in the secondary succession. It becomes established in pure, even-aged stands usually after fire. Hardwoods develop as an understory and become dominant when the pine stand disintegrates (14).

In the pocosins, pond pine follows Atlantic white-cedar where the cedar is killed by fire; however, if the fire is light and the first in a long time, cedar becomes reestablished (3). Because of its sprouting ability, pond pine

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10/ Schumacher, F. X., and Coile, T. S. Yield of pond pine in standard cords for the 50 to 60 year age class. 1949. (Unpublished manuscript, School of Forestry, Duke University.)

11/ See footnote 10.

survives wet-season fires, even when severely defoliated, but severe dry-season fires eliminate it, leaving a stand of sprout hardwoods. Repeated fires on poorly drained mineral soil eventually result in a grass-sedge bog, or "savannah." Frequent burning in evergreen-shrub bog eventually produces an *Aristida-Vaccinium* community.

SPECIAL FEATURES

Data on the oleoresin constitution of pond pine are incomplete, but a trial analysis gave the following results (13):

Density	0.8478^{20}
Index of refraction	1.4734^{20}
Specific rotation, degrees	-105.5
Turpentine yield, percent	about 20
Chemical composition of turpentine, percent	80-90 limonene

RACES AND HYBRIDS

Since pond pine has been studied very little, no recorded information exists regarding geographic races or other kinds of genetic variation. However, experienced observers believe that a natural hybrid of pond pine and loblolly pine occurs where these species are closely associated.[12/] These two species have been artificially cross-pollinated and the progeny are growing at the Westvaco Experimental Forest, near Georgetown, South Carolina (1).

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by

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VOLUME DETERMINATIONS FOR SECOND-GROWTH SLASH AND LONGLEAF PINE IN NORTHEAST FLORIDA

by

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Faulty estimates of merchantable height undoubtedly have contributed more to erroneous estimates of volume and growth than any other single factor. Such errors, especially when repeated in periodic inventories, undermine the value of volume and growth estimates in research and in practice. These errors can be reduced by the use of volume tables based on total height. Toward this end, a study was made of the relationship of the merchantable volume of longleaf and slash pine to total height and other tree characteristics.

The characteristics used in this study, in addition to total height, were diameter breast high (d.b.h.), form, and crown ratio. Girard's form class was used to express the form of saw-log trees, and form quotient[1/] to express the form of pulpwood trees.

Measurements were taken on 333 felled trees within a 40-mile radius of Olustee, Florida. The trees were reasonably straight, single-stemmed, and showed no evidence of injury or wood chipping for naval stores. Merchantable sawtimber top was taken at 8 inches d.o.b. unless excessive limbiness prevented full utilization. Merchantable pulpwood top was set at 4 inches d.o.b. Only unusual crookedness or severe limbiness restricted utilization up to that point. The measurements were recorded on Forest Service Form 558a, and the volumes for each tree computed therefrom.

A regression analysis of the volume data was made to determine a suitable equation form, using the variables D^2, H, F, and CR,[2/] and their appropriate products in the light of their effect upon or significant contribution to the precision of estimate in both cubic and board volume.

CUBIC VOLUMES

The most significant variable in the complete regression of characteristics affecting the cubic-foot volume of slash and longleaf pine was the product D^2HF. After the effect of this combined variable was removed, however, other variables were found that still contributed significantly to the precision of the estimate, but to a much lesser degree.

1/ Form quotient as used in this study is the ratio of d.i.b. at the midpoint (between breast height and merchantable height) to d.b.h.

2/ Where D is diameter at breast height in inches, H is total height of tree in feet, F is form class or form quotient in percent, and CR is crown ratio in percent.

Slash Pine

The variables contributing to the cubic-foot volume estimates of slash pine pulpwood (5.0-12.9 inches d.b.h.), in order of their importance, were D^2HF^{**}, D^2H^{**}, D^2HCR^{*}, and D^{2*}.[3/] The coefficient of determination for this set of variables was 99.5 percent, and the regression equation becomes:

$$\text{Vol. (cubic feet)} = .00003(D^2HF) + .00057(D^2H) - .000005(D^2HCR) + .02457(D^2) - 1.704.$$

Accurate measurements of form and crown ratio, however, are difficult to obtain, and often costly. Since the significant variables consisted primarily of D^2 and H, a second regression was computed using only one independent variable, D^2H. The coefficient of determination for this single variable was 99.1 percent, and the short regression equation becomes:

$$\text{Vol. (cubic feet)} = .002853D^2H - .976.$$

A slash pine volume table expressed in cubic feet and based on this equation may be found in the Appendix.

Longleaf Pine

D^2HF^{**}, F^{**}, and D^2HCR^{*}, in that order, contributed significantly to the determination of cubic-foot volume estimates for longleaf pine pulpwood. The coefficient of determination was calculated as 99.3 percent, and the regression equation becomes:

$$\text{Vol. (cubic feet)} = .00004345(D^2HF) - .052(F) - .00000313(D^2HCR) + 1.219.$$

Since both D^2 and H are already included in two of the three significant variables, and since a combined D^2H variable was used so successfully for slash pine determinations, this single independent variable was used again. The coefficient of determination was 98.5 percent, and the short regression equation becomes:

$$\text{Vol. (cubic feet)} = .00287D^2H - .956.$$

A longleaf pine volume table expressed in cubic feet and based on this equation may be found in the Appendix. Since the short equations for longleaf and slash pine were so much alike, a combined regression using the single variable D^2H for both species was run. The coefficient of determination was 98.8 percent, and the combined short regression equation becomes:

$$\text{Vol. (cubic feet)} = .00286D^2H - .956.$$

3/ * - Significant at the 5 percent level.
** - Significant at the 1 percent level.

The table based on this equation is also found in the Appendix.

Cubic-foot volumes may occasionally be needed for sawtimber-size trees. The most significant variable of those tested was D^2HF, but the coefficient of determination was reduced only 1 percent by using D^2H as the single independent variable in the regression. Cubic-foot volumes for saw-log-size slash and longleaf pine may also be found in the Appendix.

BOARD VOLUMES

D^2HF was also the most significant variable in the complete regression of characteristics affecting the board-foot volume content of slash and longleaf pine, measured either by the Scribner or International $\frac{1}{4}$-inch Rule.

Slash Pine

The variables contributing to the board-foot volume estimates of slash pine sawtimber (+9.0 inches d.b.h.[4]), Scribner Rule, in order of their importance were D^2HF**, D^2H**, and HF**. Their coefficient of determination was 97.8 percent, and the regression equation becomes:

$$\text{Vol. (board-feet, Scribner)} = .0003131(D^2HF) - .01005(D^2H) - .0077(HF) - 12.05.$$

Using board-foot volume estimates from the International $\frac{1}{4}$-inch Rule, D^2HF**, H**, and D^2H* were significant contributors, in that order. Their coefficient of determination was 98.1 percent, and the regression equation becomes:

$$\text{Vol. (board-feet, Int. } \tfrac{1}{4}\text{-inch)} = .0002586(D^2HF) - 1.1(H) - .00392(D^2H) + 4.702.$$

The significance of the combined variable D^2H was evident again. The coefficient of determination for this single variable was 94.2 percent for Scribner volumes and 95.7 percent for International $\frac{1}{4}$-inch volumes. The short regression equations are:

$$\text{Vol. (board-feet, Scribner)} = .01343D^2H - 45.45.$$

$$\text{Vol. (board-feet, Int. } \tfrac{1}{4}\text{-inch)} = .01495D^2H - 60.25.$$

A local volume table for slash pine sawtimber based on these equations is in the Appendix.

4/ Sawtimber trees must have at least one 16-foot log to an 8-inch top outside bark.

Longleaf Pine

The significant characteristics contributing to volume estimates of longleaf trees are almost identical to those for slash pine. For Scribner volumes, D^2HF^{**}, H^{**}, F^{*}, and D^2H^{*} in that order contributed significantly. The coefficient of determination for these variables was 96.2 percent, and the regression equation becomes:

$$\text{Vol. (board-feet, Scribner)} = -.00006(D^2HF) - .8899(H) + 3.1612(F) + .019829(D^2H) - 243.662$$

For International $\frac{1}{4}$-inch volumes, D^2HF^{**}, and H^{**} were the significant variables of those tested. Their coefficient of determination was 96.4 percent, with a regression equation as follows:

$$\text{Vol. (board-feet, Int. } \tfrac{1}{4}\text{-inch)} = .0002(D^2HF) - 1.053(H) + 7.320.$$

Using the single variable D^2H in a regression as before, the coefficient of determination for Scribner volumes was 92.3 percent and that for International $\frac{1}{4}$-inch volumes 93.4 percent. The short regression equations are:

$$\text{Vol. (board-feet, Scribner)} = .01485D^2H - 48.20$$

$$\text{Vol. (board-feet, Int. } \tfrac{1}{4}\text{-inch)} = .01662D^2H - 63.97.$$

A local volume table for longleaf pine sawtimber based on these equations is in the Appendix.

TOPWOOD

That portion of the saw-log tree above an 8-inch top to an upper merchantability of 4 inches, outside bark, is considered topwood. In this study, the entire cubic-foot content of this portion of the tree was considered merchantable for pulpwood or cordwood, without regard to length.

Using the variables D^2 and H, and their combined effect, a regression analysis indicated $\frac{H}{D^2}$ as the only significant variable. This relationship was true for both longleaf and slash pine topwood. The coefficient of determination for longleaf was 71.0 percent and for slash 68.8 percent. The regression equations were:

Longleaf

$$\text{Topwood volume (cubic feet)} = 11.08\left(\frac{H}{D^2}\right) + .2257$$

Slash

$$\text{Topwood volume (cubic feet)} = 13.06\left(\frac{H}{D^2}\right) - .1268$$

Local topwood tables may be found in the Appendix. A combined table for both longleaf and slash pine is also presented for use in topwood determinations in mixed stands where species are not designated. An estimate of topwood volumes per MBM of sawtimber, by average stand diameters, may also be found in the Appendix.

This method of determining topwood is applicable only in second-growth stands where an 8-inch merchantable sawtimber top is strictly adhered to. If board-foot volume is obtained from above an 8-inch top or if other volume tables are used in estimating the board-foot content, these ratios of topwood to sawtimber volume will not apply.

In addition, old-growth longleaf pines are usually so flattopped that they contain no merchantable topwood, and no topwood determinations are recommended for stands of this nature. Longleaf pine above 16 inches d.b.h. and slash pine above 18 inches d.b.h. have such small quantities of merchantable topwood that determinations are seldom advisable.

CONCLUSIONS

Although the combined variable D^2HF proved to be most significant in the determination of cubic- and board-foot volumes for slash and longleaf pine in northeast Florida, the use of the single variable D^2H did not reduce the coefficient of determination to any appreciable degree.

Diameter and total height measurements are both easy to obtain. Diameter may be measured or estimated, depending on the number of trees involved and the accuracy desired. Total height can be measured with an Abney level or hypsometer. A sample of total height usually suffices, with just enough samples to construct a reliable height-diameter curve.

The effect of form will usually be reflected in the height-diameter relationship, but in certain instances, extremes in form may require adjustments in volume estimates. Under these circumstances, volumes for a given diameter class can be computed from the complete regression equations, which include a measurement of form.

Volume determinations of this nature find their greatest application in multiple-product sales or inventories, which consider the entire tree rather than a specific product. Careful measurements and estimates, and adherence to merchantable standards as herein described, should result in more reliable estimates of volume and growth.

Table 1.--Slash pine volume table--cubic feet [1/]

D.b.h. [2/] (inches)	Total height--feet 35	40	45	50	55	60	65	70	75	80	85	90	95
5.0	1.5	1.9	2.2	2.6	2.9	3.3	3.7	4.0					
5.5	2.0	2.5	2.9	3.3	3.8	4.2	4.6	5.1					
6.0	2.6	3.1	3.6	4.2	4.7	5.2	5.7	6.2					
6.5	3.2	3.8	4.4	5.1	5.7	6.3	6.9	7.5	8.1				
7.0	3.9	4.6	5.3	6.0	6.7	7.4	8.1	8.8	9.5				
7.5	4.6	5.4	6.2	7.0	7.8	8.7	9.5	10.3	11.1	11.9			
8.0	5.4	6.3	7.2	8.2	9.1	10.0	10.9	11.8	12.7	13.6			
8.5	6.2	7.3	8.3	9.3	10.4	11.4	12.4	13.5	14.5	15.5	16.5		
9.0	7.1	8.3	9.4	10.6	11.7	12.9	14.0	15.2	16.4	17.5	18.7		
9.5		9.3	10.6	11.9	13.2	14.5	15.8	17.0	18.3	19.6	20.9		
10.0			11.9	13.3	14.7	16.1	17.6	19.0	20.4	21.8	23.3		
10.5			13.2	14.8	16.3	17.9	19.5	21.0	22.6	24.2	25.8		
11.0				16.3	18.0	19.7	21.5	23.2	24.9	26.6	28.4	30.1	
11.5				17.9	19.8	21.7	23.5	25.4	27.3	29.2	31.1	33.0	
12.0				19.6	21.6	23.8	25.7	27.8	29.8	32.0	33.9	36.0	38.0
12.5				21.3	23.5	25.8	28.0	30.2	32.5	34.7	36.9	39.1	41.2
13.0				23.6	25.8	28.0	30.2	32.4	34.6	36.7	38.9	41.1	43.3
13.5				25.3	27.7	30.1	32.4	34.8	37.1	39.5	41.9	44.2	46.6
14.0				27.1	29.7	32.2	34.7	37.3	39.8	42.3	44.9	47.4	50.0
14.5				29.0	31.7	34.4	37.1	39.8	42.6	45.3	48.0	50.7	53.5
15.0				30.9	33.8	36.7	39.6	42.5	45.4	48.3	51.3	54.2	57.1
15.5				32.8	36.0	39.1	42.2	45.3	48.4	51.5	54.6	57.7	60.8
16.0				34.9	38.2	41.5	44.8	48.1	51.5	54.8	58.1	61.4	64.7
16.5				37.0	40.5	44.0	47.6	51.1	54.6	58.1	61.7	65.2	68.7
17.0				39.2	42.9	46.6	50.4	54.1	57.9	61.6	65.4	69.1	72.8
17.5				41.4	45.4	49.3	53.3	57.3	61.2	65.2	69.2	73.1	77.1
18.0				43.7	47.9	52.1	56.3	60.5	64.7	68.9	73.1	77.3	81.5
18.5				46.0	50.5	54.9	59.3	63.8	68.2	72.6	77.1	81.5	85.9
19.0				48.5	53.2	57.8	62.5	67.2	71.9	76.5	81.2	85.9	90.6
19.5				51.0	55.9	60.8	65.7	70.7	75.6	80.5	85.4	90.4	95.3
20.0				53.5	58.7	63.9	69.1	74.2	79.4	84.6	89.8	95.0	100.1

1/ To a 4-inch top, outside bark.
2/ Volume for d.b.h. classes up to 12.5 inches were computed from the pulpwood regression equation; volumes for d.b.h. classes 13.0 inches and above were computed from saw-log regression equations.

Table 2.--Longleaf pine volume table--cubic feet [1/]

D.b.h. [2/] (inches)	Total height--feet 35	40	45	50	55	60	65	70	75	80	85	90	95
5.0	1.6	1.9	2.3	2.6	3.0	3.3	3.7	4.1					
5.5	2.1	2.5	3.0	3.4	3.8	4.3	4.7	5.1					
6.0	2.7	3.2	3.7	4.2	4.7	5.2	5.8	6.3					
6.5	3.3	3.9	4.5	5.1	5.7	6.3	6.9	7.5	8.1				
7.0	4.0	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.6				
7.5	4.7	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.0			
8.0	5.5	6.4	7.3	8.2	9.1	10.1	11.0	11.9	12.8	13.7			
8.5	6.3	7.3	8.4	9.4	10.4	11.5	12.5	13.6	14.6	15.6	16.7		
9.0	7.2	8.3	9.5	10.7	11.8	13.0	14.2	15.3	16.5	17.6	18.8		
9.5		9.4	10.7	12.0	13.3	14.6	15.9	17.2	18.5	19.8	21.1		
10.0			12.0	13.4	14.8	16.3	17.7	19.1	20.6	22.0	23.4		
10.5			13.3	14.9	16.4	18.0	19.6	21.2	22.8	24.4	25.9		
11.0				16.4	18.1	19.9	21.6	23.3	25.1	26.8	28.6	30.3	
11.5				18.0	19.9	21.8	23.7	25.6	27.5	29.4	31.3	33.2	
12.0				19.7	21.8	23.8	25.9	28.0	30.0	32.1	34.1	36.2	38.2
12.5				21.5	23.7	26.0	28.2	30.4	32.7	34.9	37.2	39.4	41.5
13.0				23.1	25.3	27.6	29.8	32.0	34.3	36.5	38.8	41.0	43.2
13.5				24.8	27.3	29.7	32.1	34.5	36.9	39.3	41.8	44.2	46.6
14.0				26.7	29.3	31.9	34.5	37.1	39.7	42.3	44.8	47.4	50.0
14.5				28.6	31.3	34.1	36.9	39.7	42.5	45.3	48.1	50.8	53.6
15.0				30.5	33.5	36.5	39.5	42.4	45.4	48.4	51.4	54.4	57.3
15.5				32.5	35.7	38.9	42.1	45.3	48.5	51.6	54.8	58.0	61.2
16.0				34.6	38.0	41.4	44.8	48.2	51.6	55.0	58.4	61.8	65.1
16.5				36.8	40.4	44.0	47.6	51.2	54.8	58.4	62.0	65.6	69.2
17.0				39.0	42.8	46.7	50.5	54.3	58.1	62.0	65.8	69.6	73.5
17.5				41.3	45.3	49.4	53.5	57.5	61.6	65.6	69.7	73.7	77.8
18.0				43.6	47.9	52.2	56.5	60.8	65.1	69.4	73.7	78.0	82.3
18.5				46.0	50.6	55.1	59.7	64.2	68.7	73.3	77.8	82.3	86.9
19.0				48.5	53.3	58.1	62.9	67.7	72.4	77.2	82.0	86.8	91.6
19.5				51.1	56.1	61.2	66.2	71.2	76.3	81.3	86.4	91.4	96.4
20.0				53.7	59.0	64.3	69.6	74.9	80.2	85.5	90.8	96.1	101.4

1/ To a 4-inch top, outside bark
2/ Volume for d.b.h. classes up to 12.5 inches were computed from the pulpwood regression equation; volumes for d.b.h. classes 13.0 inches and above were computed from saw-log regression equations.

Table 3.--Slash and longleaf pine pulpwood volume table--cubic feet 1/

D.b.h. (inches)	Total height-- feet											
	35	40	45	50	55	60	65	70	75	80	85	90
5.0	1.5	1.9	2.2	2.6	2.9	3.3	3.7	4.0				
5.5	2.0	2.5	2.9	3.3	3.8	4.2	4.6	5.1				
6.0	2.6	3.1	3.6	4.2	4.7	5.2	5.7	6.2				
6.5	3.2	3.8	4.4	5.1	5.7	6.3	6.9	7.5	8.1			
7.0	3.9	4.6	5.3	6.0	6.7	7.4	8.1	8.8	9.5			
7.5	4.6	5.4	6.2	7.0	7.8	8.7	9.5	10.3	11.1	11.9		
8.0	5.4	6.3	7.2	8.2	9.1	10.0	10.9	11.8	12.7	13.6		
8.5	6.2	7.3	8.3	9.3	10.4	11.4	12.4	13.5	14.5	15.5	16.6	
9.0	7.1	8.3	9.4	10.6	11.7	12.9	14.1	15.2	16.4	17.5	18.7	
9.5		9.3	10.6	11.9	13.2	14.5	15.8	17.1	18.4	19.7	21.0	
10.0			11.9	13.3	14.7	16.2	17.6	19.0	20.5	21.9	23.3	
10.5			13.2	14.8	16.4	17.9	19.5	21.1	22.7	24.3	25.8	
11.0				16.3	18.0	19.8	21.5	23.2	25.0	26.7	28.5	30.2
11.5				17.9	19.8	21.7	23.6	25.5	27.4	29.3	31.2	33.1
12.0				19.6	21.7	23.8	25.8	27.9	29.9	32.0	34.1	36.1
12.5				21.4	23.6	25.9	28.1	30.3	32.6	34.8	37.0	39.3

1/ To a 4.0-inch top, outside bark.

Table 4.--Slash pine sawtimber volume table--board-feet (Scribner) 1/

D.b.h. (inches)	Total height-- feet										
	45	50	55	60	65	70	75	80	85	90	95
9.0		9	14	20	25	31	36	42	47	52	58
9.5		15	21	27	33	39	45	52	58	[illegible]	70
10.0	15	22	23	35	42	49	55	62	69	75	82
10.5	21	29	[illegible]	43	51	58	66	73	80	88	95
11.0	28	36	44	52	60	68	[illegible]	85	93	101	109
11.5	35	43	52	61	70	79	88	97	106	114	123
12.0	42	51	61	71	80	90	100	109	119	129	138
12.5	49	60	70	81	91	101	112	122	133	143	154
13.0	57	68	79	91	102	113	125	136	148	159	170
13.5	65	77	89	101	114	126	138	150	163	175	187
14.0	73	86	99	113	126	139	152	165	178	192	205
14.5	82	96	110	124	138	152	166	180	195	209	223
15.0	91	106	121	136	151	166	181	196	211	227	242
15.5	100	116	132	148	164	180	197	213	229	245	261
16.0	109	127	144	161	178	195	212	230	247	264	281
16.5	119	137	156	174	192	211	229	247	265	284	302
17.0	129	149	168	187	207	226	246	265	285	304	323
17.5	140	160	181	201	222	242	263	284	304	325	345
18.0	150	172	194	216	237	259	281	303	324	346	368
18.5	161	184	207	230	253	276	299	322	345	368	391
19.0	173	197	221	245	270	294	318	342	367	391	415
19.5	184	210	235	261	287	312	338	363	389	414	440
20.0	196	223	250	277	304	331	357	384	411	438	465

1/ To an 8-inch top, outside bark

Table 5.--Slash pine sawtimber volume table--board-feet (Int. ¼-inch) 1/

D.b.h. (inches)	Total height-- feet										
	45	50	55	60	65	70	75	80	85	90	95
9.0				12	19	25	31	37	43	49	55
9.5			14	21	27	34	41	48	54	61	68
10.0		15	22	29	37	44	52	59	67	74	82
10.5	14	22	30	39	47	55	63	72	80	88	96
11.0	21	30	39	48	57	66	75	85	94	103	112
11.5	29	39	49	58	68	78	88	98	108	118	128
12.0	37	47	58	70	80	90	101	112	123	134	144
12.5	45	57	68	80	92	103	115	127	139	150	162
13.0	53	66	79	91	104	117	129	142	155	167	180
13.5	62	76	90	103	117	131	144	158	171	185	199
14.0	72	86	101	116	130	145	160	174	189	204	218
14.5	81	97	113	128	144	160	176	191	207	223	238
15.0	91	108	125	142	159	175	192	209	226	243	259
15.5	101	119	137	155	173	191	209	227	245	263	281
16.0	112	131	150	170	189	208	227	246	265	284	303
16.5	123	143	164	184	204	225	245	265	286	306	326
17.0	134	156	177	199	221	242	264	285	307	329	350
17.5	146	169	192	215	237	260	283	306	329	352	375
18.0	158	182	206	230	255	279	303	327	352	376	400
18.5	170	196	221	247	272	298	324	349	375	400	426
19.0	183	210	237	264	291	318	345	372	399	426	453
19.5	196	224	252	281	309	[illegible]	366	395	423	451	480
20.0	209	239	269	298	327	[illegible]	388	41[illegible]	448	478	50[illegible]

1/ To an 8-inch top, outside bark.

Table 6.--Longleaf pine sawtimber volume table--board-feet (Scribner) 1/

D.b.h. (inches)	Total height-- feet										
	45	50	55	60	65	70	75	80	85	90	95
9.0			18	24	30	36	42	48	54	60	66
9.5		19	26	32	39	46	52	59	65	72	79
10.0	19	26	34	41	48	5[illegible]	63	71	78	85	93
10.5	26	34	42	50	5[illegible]	66	75	83	91	99	107
11.0	33	42	51	60	69	7[illegible]	87	9[illegible]	105	114	123
11.5	40	50	60	70	80	89	99	109	119	129	138
12.0	48	59	69	80	91	102	112	123	134	144	155
12.5	56	68	79	91	103	114	125	137	149	161	172
13.0	65	77	90	102	115	128	140	153	165	178	190
13.5	74	87	101	114	128	141	155	168	182	195	209
14.0	83	97	112	126	141	15[illegible]	170	185	199	214	228
14.5	92	108	124	139	155	170	186	202	217	233	248
15.0	102	119	136	152	169	186	202	219	236	253	269
15.5	112	130	148	166	184	202	219	237	255	273	291
16.0	123	142	161	180	199	218	237	256	275	294	313
16.5	134	154	174	194	215	235	255	275	295	316	336
17.0	145	166	188	209	231	252	274	295	317	338	360
17.5	156	179	202	225	247	270	293	316	338	361	384
18.0	168	192	216	240	265	289	313	337	361	385	409
18.5	181	206	231	257	282	30[illegible]	333	358	384	409	435
19.0	19[illegible]	220	247	273	300	327	354	381	407	434	461
19.5	206	234	262	291	319	347	375	404	432	460	488
20.0	219	249	278	30[illegible]	[illegible]	368	397	427	457	48[illegible]	51[illegible]

1/ To an 8-inch top, outside bark.

Table 7.--Longleaf pine sawtimber volume table--board-feet (Int. ¼-inch)[1/]

D.b.h. (inches)	Total height-- feet										
	45	50	55	60	65	70	75	80	85	90	95
9.0				17	23	30	37	44	50	57	64
9.5			15	26	33	41	48	56	[illegible]	71	78
10.0		19	27	36	44	52	61	69	77	85	94
10.5	18	28	37	46	55	64	73	82	92	101	110
11.0	26	36	46	57	67	77	87	97	107	117	127
11.5	35	46	57	68	79	90	101	112	123	134	145
12.0	44	56	68	79	91	103	115	127	139	151	[illegible]
12.5	53	66	79	92	105	118	131	144	[illegible]	169	182
13.0	62	76	90	104	118	132	146	160	174	188	203
13.5	72	87	102	118	133	148	163	178	[illegible]	208	223
14.0	82	99	115	131	148	164	180	196	213	229	245
14.5	93	111	128	145	163	180	198	215	[illegible]	250	268
15.0	104	123	141	160	179	197	216	235	[illegible]	272	291
15.5	115	135	155	175	195	215	235	255	275	295	315
16.0	127	149	170	191	212	233	255	276	297	318	340
16.5	139	162	185	207	230	252	275	298	320	343	365
17.0	152	176	200	224	248	272	296	320	344	368	392
17.5	165	190	216	241	266	292	317	343	368	394	419
18.0	178	205	232	259	286	313	339	366	393	420	447
18.5	192	220	249	277	305	334	362	391	419	447	476
19.0	206	236	266	296	326	355	385	415	445	475	505
19.5	220	252	283	315	346	378	409	441	473	504	536
20.0	235	268	301	334	368	401	434	467	500	534	567

1/ **To an 8-inch top, outside bark.**

Table 8.--Slash pine topwood volumes[1/]

D.b.h. (inches)	Total height-- feet							
	50	55	60	65	70	75	80	85
			- - - - - Cubic feet - - - - -					
10	6.4	7.1	7.7	8.4	9.0	9.7	10.3	11.0
12	4.4	4.9	5.3	5.8	6.2	6.7	7.1	7.6
14	3.2	3.5	3.9	4.2	4.5	4.9	5.2	5.5
16	2.4	2.7	2.9	3.2	3.4	3.7	4.0	4.2
18	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3
			- - - - - Cords[2/] - - - - -					
10	.071	.079	.086	.093	.100	.108	.114	.122
12	.049	.054	.059	.064	.069	.074	.079	.084
14	.036	.039	.043	.047	.050	.054	.058	.061
16	.027	.030	.032	.036	.038	.041	.044	.047
18	.021	.023	.026	.028	.030	.032	.034	.037

1/ That portion of the volume of a sawtimber tree between an 8-inch and a 4-inch d.o.b. point.

2/ To convert cubic-foot volume to cords, a ratio of 90 cubic feet of solid wood to a standard cord of 128 cubic feet was employed.

Table 9.--Longleaf pine topwood volumes 1/

D.b.h. (inches)	Total height--feet							
	50	55	60	65	70	75	80	85
				Cubic feet				
10	5.8	[illegible]	6.9	7.4	8.0	8.5	9.1	9.6
12	4.1	[illegible]	[illegible]	5.2	5.6	6.0	6.4	6.8
14	3.1	[illegible]	[illegible]	[illegible]	4.1	4.5	4.7	5.0
16	2.4	2.6	2.8	3.0	3.3	3.5	3.7	3.9
				Cords 2/				
10	[illegible]	.070	[illegible]	.082	.089	.094	.101	.107
12	[illegible]	.050	.053	[illegible]	.062	.067	.071	.075
14	[illegible]	.037	.040	.043	.045	.050	.052	.055
16	.027	.029	.031	.033	.037	.039	.041	.043

1/ That portion of the volume of a sawtimber tree between an 8-inch and a 4-inch d.o.b. point.

2/ To convert cubic-foot volume to cords, a ratio of 90 cubic feet of solid wood to a standard cord of 128 cubic feet was employed.

Table 10.--Slash-longleaf pine topwood volumes 1/

D.b.h. (inches)	Total height--feet							
	50	55	60	65	70	75	80	85
				Cubic feet				
10	6.1	6.7	[illegible]	7.8	[illegible]	9.0	9.6	10.2
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.3	6.7	7.1
14	[illegible]	[illegible]	[illegible]	4.1	[illegible]	4.7	5.0	[illegible]
16	[illegible]	2.8	[illegible]	3.2	3.4	3.7	[illegible]	4.1
18	2.1	2.2	2.4	2.6	2.8	3.0	3.1	3.3
				Cords 2/				
10	.067	.074	.081	.087	[illegible]	.100	.107	.113
12	.048	.052	.057	.061	.065	.070	.074	.079
14	.036	[illegible]	.042	.045	.049	.052	.055	.059
16	.028	.031	.033	.036	.038	.041	.043	.045
18	.023	.024	.027	.029	.031	.033	.034	.037

1/ That portion of the volume of a sawtimber tree between an 8-inch and a 4-inch d.o.b. point.

2/ To convert cubic-foot volume to cords, a ratio of 90 cubic feet of solid wood to a standard cord of 128 cubic feet was employed.

Table 11.--Estimates of topwood per MBM (Scribner) by average stand diameters 1/

Average stand d.b.h. (inches)	Slash	Longleaf
	- - - Cords - - -	
11	1.1	.8
12	.9	.7
13	.6	.5
14	.4	.3
15	.2	.1

1/ Based on timber sales on the Olustee Experimental Forest using local sawtimber and topwood regression equations.

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June 1958

Forest Insect Conditions in the Southeast During 1957

by

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and R. J. Kowal

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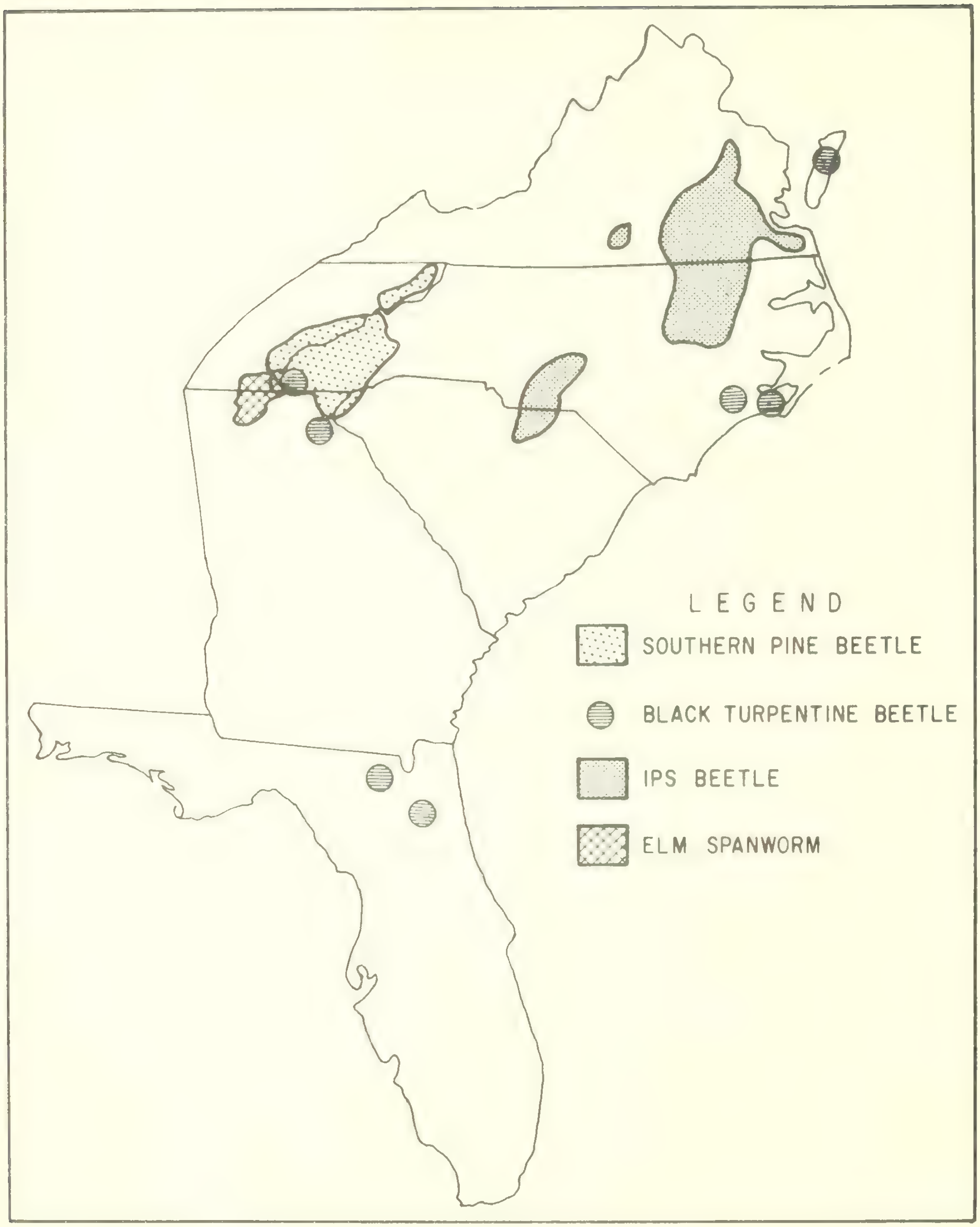

Figure 1.--Major forest insect epidemics in the Southeast in 1957.

FOREST INSECT CONDITIONS IN THE SOUTHEAST DURING 1957

by

W. F. McCambridge, W. P. Nagel, and R. J. Kowal

INTRODUCTION

Forest insect conditions continued to improve generally in the Southeast during 1957 (fig. 1) despite the fact that Ips beetles killed an estimated 10 million board-feet during one epidemic period and southern pine beetles destroyed over 95,000 trees in the Southern Appalachian Mountains.

Extremely cold weather in December killed a high percentage of southern pine beetle broods.

The black turpentine beetle remained in outbreak status on the Hoffman Forest in eastern North Carolina. In Florida the beetle was much less active than in 1956.

The elm spanworm (snow-white linden moth) was the only defoliator in outbreak status, although local infestations of sawflies, especially in Florida, were causing some concern.

During 1957 a cooperative insect survey plan for Florida was developed and two semi-annual aerial surveys conducted. These surveys were under the direction of the Florida Forest Service, with the State Plant Board and U. S. Forest Service cooperating. During these surveys over ten million acres of forest land in northern Florida were covered by 2.5-percent intensity.

The summary of insect conditions presented in this report includes only those infestations which caused, or were capable of causing, serious economic losses. A few minor insects of special interest are also noted. This report is made up to a considerable extent from information submitted directly to this office by cooperators and from reports and information submitted by pest control foresters, especially from Virginia and North Carolina. The summary of formal cooperative reports is presented in table 1.

While the number of reports received by this Station in 1957 is less than those submitted in 1956, insect conditions during the year were under much greater scrutiny. In Virginia, field reports from each district are summarized monthly by the insect and disease specialist in the Division of Forestry. Copies of these reports are submitted to this office. In addition, the associate extension entomologist puts out a monthly economic insect report containing a section devoted to forest insects. A somewhat similar but less formal system exists in North Carolina, and this office is kept informed of all serious infestations by frequent written and verbal communication. The State of Florida is

rapidly developing an extensive reporting system and this year has developed an intensive aerial sampling survey for the detection of insect infestations and for an appraisal of insect losses.

Table 1.--Cooperative insect conditions reports received from federal, state, and private sources during 1957

State	Reports	State	Reports
	Number		Number
Virginia	2	Georgia	1
North Carolina	16	Florida	3
South Carolina	4	Tennessee (eastern)	2
		Total	30

SOUTHERN PINE BEETLE

Southern pine beetle activity in the Southeast was mainly confined to the epidemic areas in the Southern Appalachian Mountains. Light to moderate attacks occurred on the South Carolina coast and in central and eastern Virginia.

The epidemic situation in the Southern Appalachians entered into its fifth consecutive year during 1957. This epidemic is centered in an 8,000-square-mile-area of western North Carolina, eastern Tennessee, northeastern Georgia, and northwestern South Carolina. It is estimated that approximately 95,000 trees containing an estimated 2-1/3 million board-feet of pine were killed by the beetle in this area. Survey estimates prior to August were based upon aerial operational surveys of the infested areas conducted by Experiment Station and control unit personnel. In August the Regional Office assumed the responsibility for these operational flights. Loss estimates since August were derived from survey reports and treating records.

Table 2 summarizes the infestation and treating records for 1957.

Though figure 2 shows an increase in the number of infested trees for 1957 over that of 1956, this is not actually a true picture. Infestation estimates for 1956 were based mainly upon information obtained from aerial surveys over control units and included few estimates of attacks on other areas of beetle activity. The estimate for 1957 is a more realistic figure in that it includes estimates in certain areas outside of control units. Such areas are chiefly in the Great Smoky Mountains National Park, where tremendous losses occurred. In reality, attacks by the southern pine beetle were not as severe or as numerous in 1957 on most control areas.

Table 2.--Southern pine beetle losses and control accomplishments during 1957 in the Southern Appalachian Mountains

Area	Trees infested	Trees treated	Volume killed [1]
	Number	Number	Thousand board-feet
Georgia			
Brasstown District	135		
Tallulah District	7,725	3,000	
Total	7,860	3,000	197
North Carolina			
Catawba District	450	19	
Cheoah District	4,605	5,877	
French Broad District	75	64	
Grandfather District	227	94	
Pisgah District	900	556	
Tusquitee District	2,835	3,102	
Asheville Basin	1,760	3,856	
Cherokee County		2,663	
Blue Ridge Parkway		124	
Cherokee Indian Reservation		155	
Total	10,852	16,510	271
South Carolina			
General Pickens District	6,083	3,110	
Total	6,083	3,110	152
Tennessee			
Hiwassee District	160		
Tellico District	6,239	5,914	
Unaka District	500		
Watauga District	500		
Great Smoky Mountains National Park	62,950	4,669	
Total	70,349	10,583	1,759
Grand Total	95,144	33,203	2,379

1/ Volume of each killed tree estimated to be 25 board-feet.

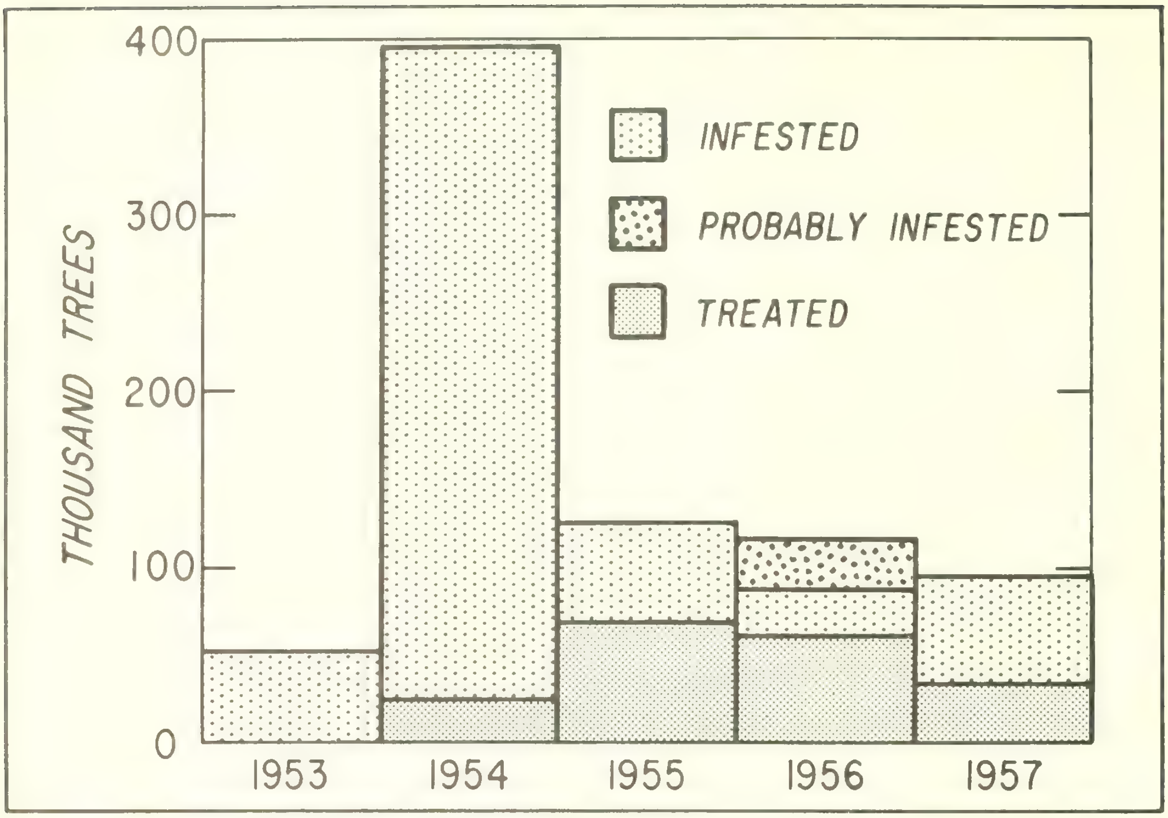

Figure 2.--Southern pine beetle epidemic within control units in the Southern Appalachian Mountains, 1953-1957. Survey estimates as compared with control accomplishments.

Direct control action was also less than in the preceding year and was at times discontinued because of scarcity of infested trees and some delays in obtaining control funds. Little salvage was accomplished by any of the control units. Unfortunately, data on the number or volumes of killed trees that were salvaged are not available. Two units, the Tellico District in Tennessee and the Tusquitee District in North Carolina, utilized burning as a control measure under restrictive conditions and in both cases it proved to be very effective and economical. This form of control is not generally recommended. Most direct control action was with a spray of 0.25 percent gamma benzene hexachloride and fuel oil applied to the bark surfaces of the infested trees. A total of 33,203 infested trees were either felled and sprayed or burned during 1957.

On December 12, 1958, during a winter which was colder than normal, temperatures fell to 0° F. and below in many locations throughout the outbreak area. This extreme cold lasted for only one day but temperatures remained well below freezing for several days.

Bark samples containing beetle broods show much variation in mortality because of stage and size of the insect and its location in the bark. Results of samples taken to date are presented in table 3. Sampling is continuing at other locations.

Table 3.--Mortality of southern pine beetle brood in the Southern Appalachian Mountains caused by low temperatures of December 12, 1957

Sample location	Minimum temperature	Mortality, all stages
	Degrees F.	Percent
General Pickens District, South Carolina	+2	41
Tusquitee District, North Carolina	-2	78
Tellico District, Tennessee	-5	72
Bent Creek, North Carolina	0	73
Asheville Basin, North Carolina	1	83

Larvae of a predator (probably Thanasimus dubius) of the family Cleridae, which is predaceous upon the southern pine beetle, survived the cold much better than did the beetle. Mortalities were about 40 percent of those sustained by the southern pine beetle.

It is hoped that woodpeckers and the clerids working on these reduced beetle populations will bring the beetles to endemic levels in some areas.

Virginia.--During 1957 there were scattered reports of small infestation centers in south-central and eastern Virginia. Groups of 3 to 5 trees were common, with an occasional infested spot running up to 60 trees. Ips beetles were frequently associated with these southern pine beetle attacks.

North Carolina.--Control activities were intermittent during the first 6 months of the year and by mid-May all operations were halted. At that time crews were unable to find trees containing living broods, and newly attacked trees had not become evident. Fading trees were first noticed in early June, at which time surveys and control operations were reactivated.

Infestations on the Catawba, French Broad, and Grandfather Districts were few and scattered in 1957. Chemical control was applied to 714 trees on these Districts. Activity on the Pisgah District was continuous but not extensive, and of the 900 trees infested 556 were sprayed. As in 1956, the highest incidence of attacks took place on the Cheoah and Tusquitee Districts. However, losses were not so great during 1957. Survey estimates place the number of attacked trees at 7,900 for these two Districts this year, compared to 19,020 in 1956. Control action was greater on the Cheoah District mainly because of the heavily infested Slickrock drainage, which had previously been inaccessible. The Tusquitee and Cheoah Districts treated 8,979 pines in 1957 as compared to 7,440 in 1956.

Approximately 10,850 pines containing 271,000 board-feet of timber were killed by the beetle in North Carolina during 1957. A total of 16,202 trees were sprayed, 6,500 of which were treated on private lands by the State of North

Carolina. Many of these trees were attacked in 1956 and not treated until 1957. During December, one district burned 180 infested trees under favorable conditions and found that such a procedure resulted in excellent control. This burning was done after a snowfall, with the potential fire hazard all but eliminated.

South Carolina.--The majority of southern pine beetle activity took place on the General Pickens District in the northwestern corner of the State. Mortality on the District in 1957 was about 6,000 trees (152,000 board-feet), compared to 8,000 trees during 1956. Some 3,110 trees were treated in 1957, whereas 7,382 had been treated in the preceding year. Many areas remained untreated at the end of 1957.

A small number of trees were attacked by the beetle in association with Ips spp. in forest stands immediately south of Georgetown. These attacks were insignificant and further activity has not been noted.

Georgia.--Beetle activity remained fairly constant throughout the year on the Tallulah District in northeastern Georgia. It was estimated that 7,700 trees containing 197,000 board-feet of timber were killed in 1957. Chemical control was used against approximately 3,000 infested trees during the year. The only other known area that had southern pine beetle attacks was detected on the Brasstown District in northern Georgia during November. About 135 infested trees were found on an aerial survey, but a subsequent ground examination revealed that few successful broods had been produced and no attacks in adjacent green timber were evident.

Tennessee.--The most active areas of the epidemic were in eastern Tennessee. Two units, the Tellico District and the Great Smoky Mountains National Park, were the only ones on which control action took place. A few attacks were observed on the Hiwassee District in the spring, but a subsequent survey showed no further spread from these trees. Light, scattered infestations were noted on the Watauga, Unaka, and Nolichucky Districts in the spring, and subsequent surveys have not been made. It is estimated that about 1,500 trees were killed on these Districts in 1957. Low timber values make control and intensive surveys on these Districts impractical.

About 6,200 trees (155,000 board-feet) were estimated to have been killed on the Tellico District in 1957. Direct control operations were carried out against 5,914, and at the end of the year several areas were in need of treatment. Control by spraying was supplemented in part by burning. Such procedure proved to be both entomologically sound as a control method and profitable to the District. Burning costs were about $0.52 per tree, whereas spraying costs were $1.19 per tree.

While the Great Smoky Mountains National Park lies in both Tennessee and North Carolina, the greater majority of attacks and control took place in Tennessee. Losses on the control units within the Park were estimated to have been 13,000 trees. In addition, it is thought that uncontrolled areas in the Park suffered a total kill of at least 50,000 pines. Infestations in these

uncontrolled areas were extremely active and numerous throughout the year. All of these additional 50,000 trees were not in Tennessee, but it is assumed that less than 10 percent occurred on the North Carolina portion of the Park.

Treating records of the Park show that 4,669 trees were sprayed during the calendar year on the control units. Lack of sufficient funds at critical periods prevented the Park from employing a more vigorous control program. At the end of the year many active spots still were in need of chemical treatment.

The large and aggressive beetle populations in the Great Smoky Mountains National Park are difficult to account for. It is known from long-standing records that southern pine beetles can be found in the western part of the Park when they are almost impossible to detect elsewhere. The area seems to be a permanent breeding ground for the beetle. It may be that vigorous strains of the beetle exist, which, in the presence of large areas of inaccessible host material, perpetuate beetle populations. These gradually reinfest nearby control units (even though the distance between untreated infestations and control units appear great enough to minimize migration). This, combined with difficulties in applying control measures, may explain why it has not been possible to keep the beetles down to a low population level.

PINE ENGRAVER BEETLE

A short-lived but very destructive outbreak of Ips beetles occurred during June, July, and August in the east-central portions of Virginia and North Carolina and in northeastern South Carolina. The outbreak was shorter in duration in some areas than in others and was scattered broadly over the region, as outlined in figure 1.

The outbreaks began in early June in the southern portion of the infestation area, developing a little later and continuing a little longer in the northern extremities.

Throughout the infestation area in North Carolina ground examinations have shown that after one initial and tremendous increase in beetle populations, adverse factors brought a sudden halt to the outbreak. Examination of the initial groups of killed trees showed: (a) broods were frequently not produced by parent beetles of the initial population buildup, (b) broods often failed to develop beyond the small larval stage, and (c) adult beetles that did develop failed to emerge.

During the short period that Ips were in outbreak status in east central Virginia and North Carolina and northeastern South Carolina, it is estimated that about 10 million board-feet of pine, chiefly loblolly, were killed.

All three species of Ips were present in these outbreak areas; namely, _Ips calligraphus_, _Ips grandicollis_, and _Ips avulsus_.

In Florida, during the fall survey Ips kills were frequently found associated with lightning-struck trees. These infestations died out shortly after the initial population buildup.

BLACK TURPENTINE BEETLE

Turpentine beetle control came to a standstill on the Osceola National Forest in Florida during the year. Less beetle activity was noted in other parts of north Florida and south Georgia. Scattered reports of light damage were received from other parts of the Southeast. In the naval stores program, measures for control of the beetle continued. A survey of operations in north Florida and south Georgia revealed that wherever control measures were being applied as recommended little tree mortality occurred.

In North Carolina a small but vigorous outbreak in the southwestern part of the State required chemical treatment and was quickly brought under control. Elsewhere in the State a full scale outbreak continues on the Hoffman Forest in the vicinity of New Bern. Continuous logging of pond pine in pocosin type has maintained high but fluctuating beetle populations. Early in the year turpentine beetles were declining. Populations remained low until midsummer. Since then they have increased, and in some logging units most of the residual trees have been killed. In contrast, uncut stands across the road were unattacked. It remains to be seen how these uncut stands will fare when there is no suitable material in the cutover areas.

In northern Georgia, the turpentine beetle has maintained high populations in stumps, with some standing trees coming under attack. Damaged trees along skidways and logging roads have suffered some mortality. During 1957, chemical control was required to treat 1,784 standing trees and 5,806 stumps.

Reports from Virginia indicated light but widespread turpentine beetle activity from time to time during 1957. No large outbreaks developed, however.

VARIABLE OAK LEAF CATERPILLAR

In 1956 this insect was in outbreak status over millions of acres in eastern Virginia. During the winter of 1956-57, prepupae were abundant in the soil. As late as June, prepupae were still abundant. For reasons not wholly known, emergence failed to take place. This condition has been characteristic of the insect in other areas of the South in the past years. During 1957, the variable oak leaf caterpillar was reported from only one small area in Warwick County.

ELM SPANWORM
(Snow-white Linden Moth)

The elm spanworm, *Ennomos subsignarius*, caused severe defoliation of hardwoods, mainly hickory and oak, again during 1957. In 1956 it was estimated that 50,000 acres in northern Georgia had been defoliated. During 1957

this epidemic center has increased to 100,000 acres, with an additional 200,000 acres of defoliation extending into southeastern Tennessee and southwestern North Carolina. Heaviest defoliation occurred mainly along the ridgetops. As yet no tree mortality has been attributed directly to the looper. Studies to determine whether any growth loss had occurred were undertaken; incomplete results indicate that some growth loss is taking place.

FIR APHID

Chermes piceae has been detected infesting Frazer fir on Mt. Mitchell. The infestation is believed of fairly recent origin and is under surveillance.

PINE SAWFLIES

Sawfly activity along the eastern shore of Virginia was negligible during 1957. This was a welcome relief, for the sawfly had been active in these areas for the past 4 years.

Elsewhere in Virginia, there were frequent reports of small active infestations, with a possible epidemic developing in the south central and southeastern sections of the State.

In South Carolina a sawfly, Neodiprion taedae linearis, was epidemic in scattered infestations of 1 to 10 acres near Union. A severe hailstorm in April when larvae were active is believed to be at least partly responsible for control of this sawfly.

In north Florida, sawfly activity increased during the year. In the fall of 1957, Neodiprion exitans (tentative identification) has been reported in five counties in north central Florida. Infestations are small and scattered with 2 to 10 trees being heavily defoliated in many groups. Loblolly pine is suffering greatest damage. (About 10 years ago this species contributed to mortality of loblolly pine in Alabama as a result of its fall feeding habit.)

A PINE LEAF CHAFER

Pachystethus oblivia was epidemic in a young plantation in eastern North Carolina in May and June 1957. This beetle was recorded in 1956 near Waycross, Georgia, and may occur frequently enough to merit some mention.

These beetles, the male of which resembles a Japanese beetle, cause damage which appears alarming in May and June. They bite a small notch near the base of needles, causing the outer sections to turn brown and droop. The great number of beetles and the flagged branches suggest a much more serious problem than that which usually develops. By midsummer the green needles have grown out, the dead terminal sections fallen off, and the seedlings or saplings look quite healthy.

PINE REPRODUCTION WEEVILS

Damage by the pales weevil, Hylobius pales, and the pitch eating weevil, Pachylobius picivorus, to young pine planted in clear-cut pine stands continued to be a cause of concern to foresters in the Southeast. However, to reduce such damage, many agencies are now dipping their seedlings in a water emulsion of 2 percent aldrin before planting.

PINE TIP MOTHS

Infestations by the Nantucket pine moth, Rhyacionia frustrana, continued at a high level throughout most of the Southeast. While they are most common on poor sites, damage on good sites has not been unusual. Little or no effort has been made to control the insect in large plantations, because no practical method has yet been developed. However, in small and valuable plantings such as seed orchards, the application of control measures is becoming increasingly common. Monthly spray applications of insecticides are usually applied during spring and summer. DDT is effective, though there is danger of a mite buildup. A water emulsion spray of 0.5 percent gamma BHC plus 2 percent malathion has been found most satisfactory for control of the tip moth and associated insects such as scales and aphids.

Infestations by another tip moth, Rhyacionia rigidana, while not nearly so common as the above, have been more prevalent than in other years. This insect appears to be confined to slash pine and attacks all ages of trees from the young seedling to large trees.

PINE PITCH MOTHS

In the spring of this year there was an abnormally widespread infection of slash pine cones by Cronartium cone rust. During studies being conducted on cone insects it was found that rust-infected cones were heavily attacked by pitch moths (Dioryctria spp.).

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Silvical Characteristics of Baldcypress

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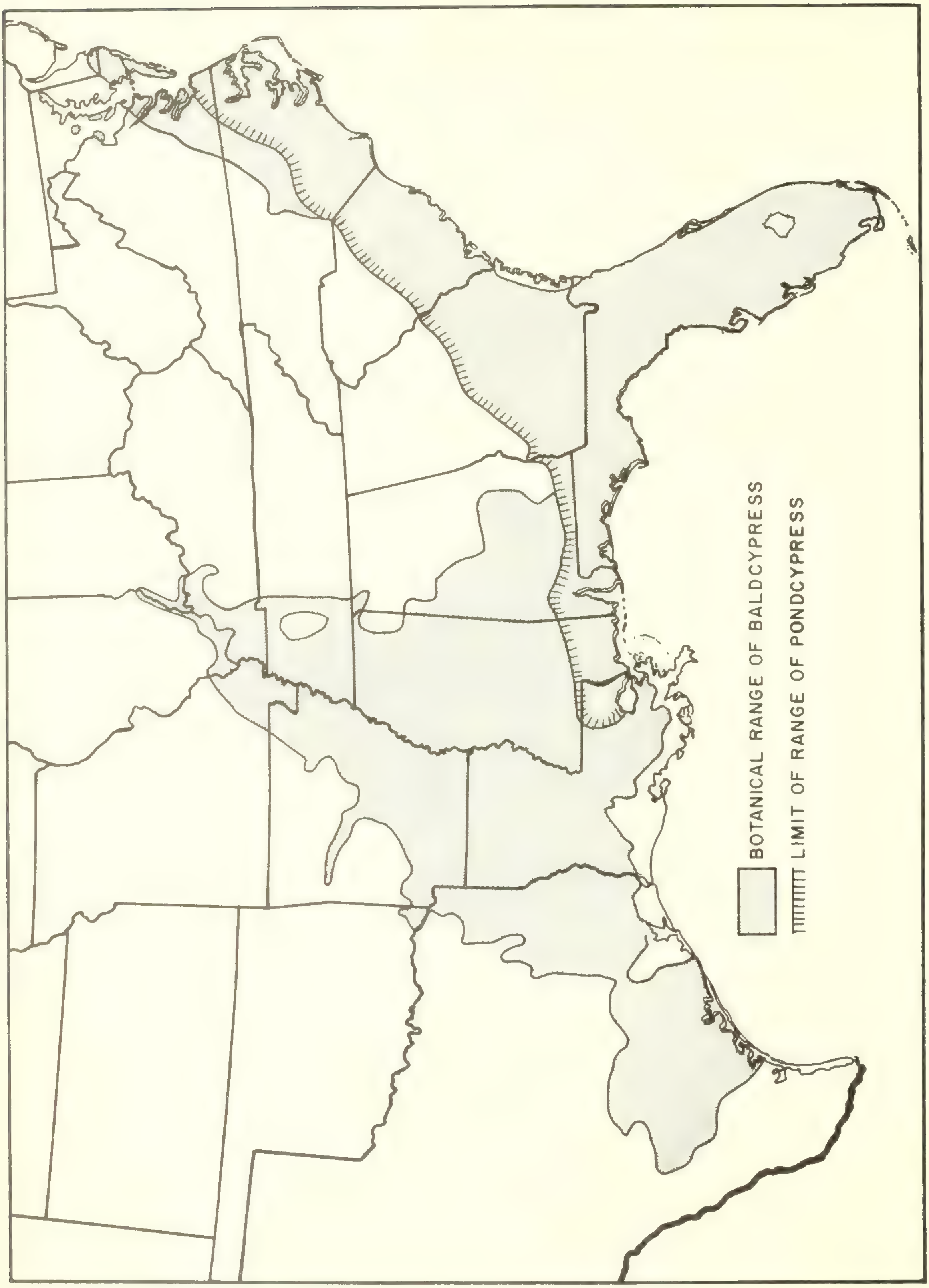
BOTANICAL RANGE OF BALDCYPRESS
LIMIT OF RANGE OF PONDCYPRESS

Figure 1.

Silvical Characteristics of Baldcypress

(*Taxodium distichum* (L.) Rich var. *distichum*)

by

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Baldcypress *(Taxodium distichum* (L.) Rich var. *distichum (15)* — also commonly called southern cypress, gulf cypress, tidewater red cypress, yellow cypress, and cypress — is perhaps one of the most unusual trees found in the South. Baldcypress grows on the wettest sites, lives for centuries, and produces a very durable wood.

The natural range of baldcypress extends along the Coastal Plain from southern Delaware to south Florida and west through southeastern Texas, almost to the Mexican border. Inland, in the Coastal Plain, it grows along the many streams of the Southeastern States and north in the Mississippi Valley to southeastern Oklahoma, southeastern Missouri, southern Illinois, and southwestern Indiana *(11, 15)* (fig. 1). Locally, baldcypress is confined to river and interior swamps, wet depressions, spring-seeps, and stream banks *(16, 24)*.

HABITAT CONDITIONS

CLIMATIC

Baldcypress grows under a considerable range of climatic conditions, but the tree reaches its maximum development in the warm, humid climate of the South *(3, 29)*. Although natural range of baldcypress does extend into regions where winters are fairly severe, very little seed matures in the extreme northern part of the range *(16)*. Individual trees planted as far north as Massachusetts and Michigan show that baldcypress will live where the temperature falls to –20° F. *(9)*.

EDAPHIC

Baldcypress is usually restricted to very wet soils consisting of mucks, clays, or the finer sands where moisture is abundant and fairly permanent. It cannot grow in poor, dry, sandy soils *(3, 9)*. Although its best growth has been found on deep, moist, fine sandy loams with moderately good drainage, baldcypress rarely occurs on such sites, presumably because of water requirements for seed germination and possibly because of competition from the more tolerant hardwood species *(12, 16)*.

Baldcypress is apparently not limited to particular soils because of soil reaction, for it occurs on Plummer and other swamp soils that vary from acid to alkaline *(7)*.

PHYSIOGRAPHIC

More than 90 percent of the natural baldcypress stands are found on flat or nearly flat topography at elevations of less than 100 feet above sea level. The upper limit of its growth in the Mississippi Valley is at an elevation of about five hundred feet. A few isolated stands are found at elevations of 1,000 to 1,750 feet bordering deep hollows on the Edwards Plateau of Texas *(9, 16)*.

BIOTIC

Baldcypress occurs both in pure stands and in mixtures with various hardwoods *(16, 21, 27)*, and is found in eight cover types of North America *(27)*.

Its chief associates are water tupelo *(Nyssa aquatica)* in the alluvial flood plains, or swamp tupelo *(Nyssa sylvatica* var. *biflora)* in the Coastal Plain swamps and estuaries *(27)*.

Other common associates are pondcypress *(Taxodium distichum* var. *mutans)*, black willow *(Salix nigra)*, swamp cottonwood *(Populus heterophylla)*, red maple *(Acer rubrum)*, Atlantic white-cedar *(Chamaecyparis thyoides)*, American elm *(Ulmus americana* var. *americana)*, green ash *(Fraxinus pennsylvanica)*, pumpkin ash *(Fraxinus profunda)*, Carolina ash *(Fraxinus caroliniana)*, waterlocust *(Gleditsia aquatica)*, redbay *(Persea borbonia)*, common persimmon *(Diospyros virginiana)*, overcup oak *(Quercus lyrata)*, and water hickory *(Carya aquatica)*.

On less moist sites or on slightly elevated ground within swamps, it may be associated with sweetgum *(Liquidambar styraciflua)*, Nuttall oak *(Quercus nuttallii)*, laurel oak *(Quercus laurifolia)*, sweetbay (*Magnolia virginiana*), loblolly pine *(Pinus taeda)*, slash pine *(Pinus elliottii)*, South Florida slash pine *(Pinus elliottii* var. *densa)*, and pond pine *(Pinus serotina) (2, 7, 16, 27, 31)*.

Baldcypress has only a few shrubby-plant associates, and these vary from region to region. For example, in south Florida they include such species as common buttonbush *(Cephalanthus occidentalis)*, stiffcornel dogwood *(Cornus stricta)*, and Walter viburnum *(Viburnum obovatum) (7)*. In contrast, the shrubby plants found with baldcypress in North Carolina include: Coast leucothoe *(Leucothoe axillaris)*, Carolina rose *(Rosa carolina)*, poison-sumac *(Toxicodendron vernix)*, stiffcornel dogwood, and possumhaw viburnum (*Viburnum nudum*) *(32)*. In many cypress swamps, ferns, vines, and epiphytes are often present and sometimes numerous *(7)*.

LIFE HISTORY

SEEDING HABITS

Flowering and fruiting. — Flower buds of baldcypress are initiated in late December or January *(22)*. Male and female flowers are borne separately on the same tree. Male flowers are minute, purple in color, and grow in drooping panicles 4 to 6 inches long at the end of the preceding year's shoots. Female flowers are inconspicuous and composed of several spirally arranged, overlapping scales, each scale bearing two ovules *(9, 12, 30)*.

These conelet-like flowers develop into cones during the first year. The cones consist of a relatively few 4-sided scales. Each scale bears two triangular seeds — both not always developed — which have thick, horny coats and irregular projecting flanges or wings along the edges *(30)*. The cones begin to lose some of their green color in September and October *(10)*, and by late October and November they mature, becoming brown and woody and measuring ½ to 1¼ inches in diameter *(9, 30)*.

Seed production and dissemination. — Baldcypress cones contain 18 to 30 seeds which ripen from October to December. The seed, together with the scales, may break away irregularly from the cone, or the entire cone may drop to the ground. Some seed is produced almost every year, and good production apparently occurs at intervals of about every 3 years *(9, 16)*.

The cones contain pockets of sticky, red, liquid resin. Probably because of the repellent effect of this resin, the seeds are seldom taken by birds, squirrels, mice, or other rodents. Because of the large size of the seed (5,000 per pound) and the relatively small wing-size, cypress seed are not dispersed by the wind. However, floodwaters spread the seed along rivers and streams, and this is the most important method of seed dissemination *(3, 8, 16)*.

VEGETATIVE REPRODUCTION

Baldcypress can reproduce by sprouts as well as by seeds *(3)*. Thrifty sprouts are generally produced from stumps of young trees, and trees 10 to 14 inches in diameter and up to 60 years of age also send up healthy sprouts, when cut during the dormant period. Stumps of trees up to 200 years old may also sprout, but the sprouts are not as vigorous and are more subject to wind damage as the stump decays. Cypress trees are often girdled 6 months to a year in advance of logging to reduce weight so that the logs will float. The stumps of these girdled trees usually do not sprout after logging *(9, 12, 16)*.

SEEDLING DEVELOPMENT

Establishment. — Seed germination usually averages 40 to 60 percent *(16)*, but it may be as low as 9 percent when conditions are poor *(30)* or as high as 87 percent when conditions are ideal *(16)*.

Under swamp conditions the best seed germination generally takes place on a sphagnum moss or a wet muck seedbed. The main requirement for germination is however an abundant supply of moisture for a period 1 to 3 months after seedfall *(16, 30)*. Water facilitates germination by allowing the hard seedcoats to swell and soften. Seeds covered with water for as long as 30 months may germinate when the water recedes. Baldcypress seeds usually fail to germinate successfully on the better-drained soils because of the lack of surface water *(16)*. The exacting requirements for moisture in early life seem to furnish the key to the whole question of baldcypress distribution *(17)*.

For seedlings of baldcypress to become established, the seed must sprout after the water recedes in the swamps, and the seedling must grow high enough the first year to stay above the floods, except for short periods *(8)*.

Early growth.—Seedlings often reach heights of 8 to 10 inches during the first season and 16 to 20 inches by the second year *(8, 16)*.

Rabbits are often attracted to young cypress seedlings and will feed heavily on them in the wintertime, causing considerable damage.[1]

[1] McKnight, J. S. Unpublished data. Delta Research Center, Southern Forest Experiment Station, New Orleans, Louisiana.

Flooding is also an important factor in the early growth of baldcypress. Growth is checked when the seedling is completely submerged by flooding, but submerged seedlings have produced new shoots when the tips were exposed to the air *(31)*. Prolonged submergence, however, may cause seedling mortality *(3, 5)*.

In a test of 2-week-old potted baldcypress seedlings, the effect of varying degrees of watering on early seedling growth was strikingly demonstrated. When the soil was filled with ground water the height growth of the seedlings was 5.2 inches after 6 weeks of testing. Another group of seedlings which had a constant supply of capillary water grew 4.6 inches. A third group of seedlings, receiving a variable water supply through daily soil surface watering, grew only 2.3 inches. Completely submerged seedlings died within 5 weeks *(17)*.

SAPLING STAGE TO MATURITY

Growth and yield. — Baldcypress is noted for its long life and the large size it attains. Cypress is also popularly considered a slow-growing tree. This belief is justified for old-growth virgin timber, but not for second-growth stands *(3, 12, 16, 28)*.

Most of the very old, very large virgin baldcypress stands have now been cut. Trees in the virgin stands were commonly 400 to 600 years old, and individual trees up to 1,200 years have been found and reported in Georgia and South Carolina *(16)*. Recently in Tennessee a baldcypress called the "Tennessee Titan" was reported to be 1,300 years old, 39 feet 8 inches in circumference, and 122.5 feet tall *(26)*. The prevailing sizes of mature trees on ordinary sites were about 36 to 60 inches d.b.h. and 100 to 120 feet in height. The largest trees on these sites were 84 to 96 inches d.b.h., with a maximum of 144 inches. Maximum heights were 140 to 150 feet, and in all cases height growth culminated before diameter *(16)*.

Increases in diameter and height of second-growth stands of baldcypress are quite rapid and compare favorably with those of many bottomland hardwood species. From data collected in the 1953-54 Forest Survey of Louisiana *(28)*, averages of 10-year diameter growth for baldcypress and other trees of the Delta region of Louisiana were compared:

D.b.h. *(inches)*	*Baldcypress* *(inches)*	*Other Delta species* *(inches)*
6 - 12	1.8	2.2
14 - 18	2.1	2.6
20 - 28	2.0	2.6

Similar diameter increases of 2 inches in every 10-year period have been reported (table 1) for second-growth stands in Maryland between the ages of 60 and 100 years *(16)*. There is good evidence based on the measurement of a large number of trees that diameter growth of baldcypress is practically the same under similar local situations throughout its range *(16)*.

Table 1.—*Average height and diameter of second-growth baldcypress in Maryland (16)*

Age (years)	Diameter	Height
	Inches	*Feet*
10	1.1	11
20	3.5	22
30	6.2	33
40	8.7	46
50	11.1	60
60	13.3	72
70	15.3	81
80	17.3	88
90	19.3	95
100	21.3	101

Height growth of baldcypress averages about 1 foot per year during its first 100 years (table 1). Height continues to increase at a slower rate during the next 100 years or so, when baldcypress reaches its maximum height *(16)*.

In the better cypress regions of the South, yields in virgin stands of 8,000 to 14,000 board-feet per acre were not uncommon over large tracts. Maximum yields on the most favorable sites were 50,000 to 60,000 board-feet per acre *(16)*. Yields for second-growth stands are not available.

The principal fungus disease of baldcypress is a brown pocket rot of the heartwood known as "peckiness" or "pecky cypress." This rot has been attributed to *Fomes geotropus (16)*. Some pathologists doubt that the fungus causing a soft white rot of hardwoods would also cause a brown pocket rot in cypress and suggest that it more closely resembles *Polyporus amarus* — the fungus that is responsible for pocket dry rot of incense cedar *(4)*. The pecky cypress fungus most frequently gains its entrance in the crown, and slowly works downward in the heartwood to the base of the tree *(16)*. Pecky cypress lumber is quite durable against decay (although not as durable as undamaged heart-cypress) because the fungus does not continue to develop in the wood after the tree is cut *(4, 16)*.

Several insects attack baldcypress, but none are reported as causing mortality. One insect — the cypress flea beetle *(Systena marginalis)* — has recently been causing severe discoloration of foliage in Georgia and Florida *(18, 25)*, and another — the cypress looper *(Anacamptodes pergracilis)* — has caused defoliation of cypress in Arkansas and Louisiana *(19)*. Several insects attack and bore into the wood of felled or girdled trees and cause serious degrade of lumber: the cypress bark borer *(Physocnemum andreae)* and the flatheaded baldcypress sapwood borer *(Acmaeodera pulchella)* damage the sapwood; the flatheaded baldcypress heartwood borer *(Trachykele lecontei)* and the flatfooted ambrosia beetle *(Platypus compositus)* damage the heartwood *(6)*.

Reaction to competition. — Baldcypress swamps are considered subclimax because they are held almost indefinitely in a subfinal stage of succession by edaphic and physiographic conditions and not by climatic ones *(20)*. The oak-hickory association is considered to be the climax in this region *(20)*.

The relative tolerance of baldcypress has not been definitely established. The species has been listed as very intolerant *(33)*, intermediate *(1, 16)*, and tolerant *(23)*.

The intermediate tolerance classification appears to fit most conditions. Although baldcypress seedlings often germinate in heavily shaded places, observations indicate that most successful stands start in openings rather than beneath crown canopies *(8, 32)*. For best growth, baldcypress requires a good degree of overhead light, but it is able to endure partial shading and still make persistent but less rapid growth *(16)*. In full stands baldcypress characteristically has a clean, smooth stem and small crown, readily pruning itself of branches *(16)*, but in poorly stocked stands it is characterized by a very limby condition above the butt-swell.

Baldcypress stands become stagnated because individual trees do not express dominance as crown canopies close. However, when cypress is released from this stand condition, it will respond and grow more rapidly *(5)*.

SPECIAL FEATURES

The most distinctive features of baldcypress are swollen, fluted trunks at the base of the tree and the occurrence of structures called "knees." These knees are vertical outgrowths from lateral roots, which vary from a few inches to several feet in height, depending on the average high-water level of the site. The main purpose of cypress knees appears to be one of anchorage. Although knees are commonly credited in literature as being aerating organs, the available evidence does not confirm this. In fact it appears that cypress trees grow as well without knees as with them *(3, 9, 12, 14, 16)*.

RACES AND VARIETIES

PONDCYPRESS

Pondcypress *(Taxodium distichum* var. *nutans* (Ait.) Sweet) *(15)*, a variety of baldcypress, closely resembles baldcypress in botanical as well as silvical characteristics. Typical specimens of each are readily identified by their leaf characteristics, but in the areas where both varieties occur, they intergrade to such an extent that it is often difficult and sometimes impossible to distinguish the two.

Pondcypress — also called pond baldcypress, black cypress, and cypress *(15, 16)* — is not as widely distributed geopraphically as baldcypress. The pondcypress range extends from southeastern Virginia to southern Florida and southeastern Louisiana (fig. 1). This tree is confined to the shallow ponds and wet areas of the Coastal Plain, and it generally does not grow in river and stream swamps *(15, 16, 23, 24)*.

Pondcypress grows under a limited range of climatic conditions, and is found only in the warm, humid climate of the Atlantic and Gulf Coastal Plain of southeastern United States.

It occupies the shallow ponds and poorly drained areas in the flatwoods of the Coastal Plain, and is rarely encountered in the floodplains of large rivers. The soils in these ponds are usually fine sands, although in some areas there may be a marl underlain by limestone *(7, 13, 16, 21)*. The altitudinal distribution of pondcypress is not as great as that of baldcypress. Most stands are found at elevations of less than 100 feet *(16)*.

Pondcypress is often the predominant tree in shallow ponds. Swamp tupelo and baldcypress are its principal associates, and pond pine, spruce pine *(Pinus glabra)*, and both varieties of slash pine are associated with it at pond borders and in slightly elevated positions within the pond *(16)*.

The seed, seeding habits, and vegetative reproduction of pondcypress are apparently very similar to baldcypress *(16, 30)*. In shallow ponds both soil and water conditions appear singularly favorable for pondcypress seed germination and early growth, for here natural reproduction is almost always uniformly abundant *(16)*.

Although little information is recorded about the growth rates of pondcypress, general observations indicate that the tree does not attain the age and large size of baldcypress, nor does it grow as fast. The smaller size and slower growth of pondcypress may be inherent or caused by poor site conditions under which the tree grows. Mattoon *(16)* points out that: "Experiments seem to show that seed from the slow-growing 'pond' form will produce inferior stock to that grown from seed from thrifty trees favorably situated."

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Control of Cull Trees and Weed Species in Hardwood Stands

by

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CONTROL OF CULL TREES AND WEED SPECIES IN HARDWOOD STANDS

by

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INTRODUCTION

Cull trees and non-commercial species have long been a problem in forest management. This is especially true in the Southern Appalachians where past logging, fire, and chestnut blight have seriously depleted the stands, leaving a high percentage of non-merchantable volume.

Hardwood cull volume is still increasing. The Southeastern Station Annual Report for 1956 states that in the southeast hardwood cull volume has increased 36 percent since 1937. The Forest Survey (8) shows that in 1955 12.5 percent of all hardwood trees in the mountain areas of North Carolina were cull. This means that about one-eighth of the growing space in these forest stands is taken up by trees that are of little or no value. Of course, it is impossible to maintain a forest free of cull trees, but the stands in their present condition are growing far less merchantable volume than they are capable of growing.

Both public and private foresters are aware of this condition and have active programs of timber stand improvement. Much work has already been done, but in view of what needs to be done, the surface has barely been scratched.

Some chemical hardwood control has been practiced for many years. The recent trend is away from the highly toxic chemicals, such as sodium arsenite, to the chemicals with little or no toxicity, such as Ammate, 2, 4, 5-T, and 2, 4-D, which have been developed since World War II. Method of application to individual trees has generally been in notches or frill-girdles made with an ax. Two recent developments, mechanical tree girdlers and improved tree injectors, are proving very effective as tools for hardwood control, and are growing in popularity.

PAST WORK

Sodium Arsenite

Sodium arsenite was one of the earliest chemicals to be used for hardwood control. It is very effective but is so highly toxic that it is dangerous to use. However, it is still being used for special cases.

Sodium arsenite is more effective than Ammate for treatment of bottomland hardwoods, such as bitter pecan (11), but is no better than Ammate for upland scrub oaks (15) ("effective" means that the crown was killed and little or no sprout growth resulted). Rushmore (16) found that sodium arsenite solution applied in holes bored in American beech killed the trees and a large percentage of the root sprouts. In later studies (17) he found that a 50-percent water solution of sodium arsenite in ax cuts spaced with 4 inches of unsevered bark between them gave fast kill for red maple when applied in summer and for beech regardless of season of application.

Sodium arsenite has been used for bark peeling on pulpwood trees. Swain (19) reports good results on white pine with impregnated paper tabs inserted under the bark. In a test in northeast Mississippi, a 40-percent aqueous solution applied in girdles gave good kill and peeling for red oak, white oak, sweetgum, shortleaf pine, and loblolly pine, but not for hickory (20). Insects and fungi caused serious damage to these treated trees, making them undesirable for pulpwood.

Ammate

Ammate has been very effective for many species when applied in cups, on stumps, or in frills. Ammate crystals in cups are more effective than Ammate solution in frills for sprout control on southern upland hardwoods, such as scrub oaks, oaks, hickories, black gum, and sweetgum (14). Ammate crystals and Ammate solution proved highly effective on post oak when applied to freshly cut stumps (12). In New Jersey, Ammate crystals were applied on stumps and in cups on dogwood, sugar maple, red maple, elm, black cherry, blackhaw, ash, and spicebush. Results were good on all species except ash and red maple (6).

2, 4, 5-T

Tests show 2, 4, 5-T is effective on many species. Various application methods have been used, but in general, oil solutions are more effective than water solutions on most species, especially during the dormant season (2, 18).

Water solutions in frills have been effective on some of the southern hardwoods (2, 10). Grano (3) found that good results were obtained on southern red oaks with a 1-percent water solution of 2, 4, 5-T in frills, regardless of season of application.

A mixture of 2, 4, 5-T in oil applied in frills on American beech, American holly, sweetgum, American hornbean, white oaks, hickories, winged elm, red oaks, and white ash resulted in a good kill on all species except American holly (7). In kill and sprout control on oaks in Missouri, an oil solution of 2, 4, 5-T applied in low frills was more effective than a waist-high notch girdle alone (13). Arend (1) reports better results with frills near the ground, and also that best results were obtained with treatments in the summer and fall.

Oil solutions of 2, 4, 5-T have been used with various girdling treatments, on stumps, and as basal sprays: McCully (9) reports satisfactory results for post oak with still another method of application: injection of the silvicide into the soil to be taken up by the roots.

Girdling

Tests show that most hardwoods larger than 11 or 12 inches in diameter can be killed by girdling without a silvicide and that very little sprouting results (5). Greth (4) found that large trees (11 inches and larger in diameter) of hickory, white oak, black oak, red oak, scarlet oak, blackjack oak, blackgum, and post oak could be killed by notch girdling with an ax, but that pole-size trees (5 to 11 inches in diameter) could not.

Many of these treatments are probably applicable in the Southern Appalachians, but tests are needed to determine which treatments, dosages, and chemicals are most effective on the mountain species.

THE STUDY

This study was designed to test several methods of killing unwanted trees and shrubs in hardwood stands in the Appalachians. The six most important species or species groups in timber stand improvement work in the mountain areas were used: red maple (Acer rubrum), sourwood (Oxydendron arboreum), laurel (Kalmia latifolia), rhododendron (Rhododendron maximum), oaks (Quercus alba, Q. velutina, Q. stellata, Q. coccinea, Q. rubra, Q. prinus, Q. falcata), and hickories (Carya ovata, C. tomentosa, C. glabra, C. cordiformis). The study was installed on the Bent Creek Experimental Forest near Asheville, North Carolina, in the spring of 1955.

Three size groups were used in the study: small, 0.6 to 4.9 inches in diameter; medium, 5.0 to 11.9 inches in diameter; and large, 12.0 inches and larger in diameter. All six species or species groups were used in the small-size group; oaks, hickories, red maple, and sourwood were used in the medium-size group; and oaks and hickories were used in the large-size group. Ten trees of each species or species group were used for each treatment, replicated on each of two blocks.

Table 1 lists the treatments used for each size group. The treatments are illustrated in figures 1 and 2.

The study was established in the spring of 1955. Examinations were made in August or September of each of the three subsequent growing seasons.

Table 1.--Treatments used for each size group

Treatment number	Treatment	Concentration
SMALL TREES (0.6 TO 4.9 INCHES IN DIAMETER)		
I	Basal spray, 2, 4, 5-T[1] (oil)	20 lbs. ahg (acid equivalent per hundred gals.)
II	Stumps (no silvicide)	---
III	Stumps, 2, 4, 5-T (oil)	20 lbs. ahg
IV	Stumps, Ammate crystals	1 tbsp./2 inches d.b.h.
MEDIUM AND LARGE TREES (5.0 INCHES AND LARGER IN DIAMETER)		
V	Cups, Ammate crystals	1 tbsp. per cup
VI	Notch-girdle (ax)	---
VII	Machine-girdle	---
VIII	Ax-frills, 2, 4, 5-T (H_2O)	8 lbs. ahg
IX	Ax-frills, 2, 4, 5-T (H_2O + wet. agt.)	8 lbs. ahg
X	Ax-frills, 2, 4, 5-T (oil)	8 lbs. ahg
XI	Machine-girdle 2, 4, 5-T (oil)	20 lbs. ahg

1/ A low-volatile butyl ether ester of 2, 4, 5-T was used.

Treatment I

The base of the tree was thoroughly wetted with the silvicide.

Treatment II

Control. The trees were cut and no silvicide was applied.

Treatment III

The trees were cut and the stumps thoroughly soaked with the silvicide.

Treatment IV

Ammate crystals were placed in the V-notches that were made when the trees were cut.

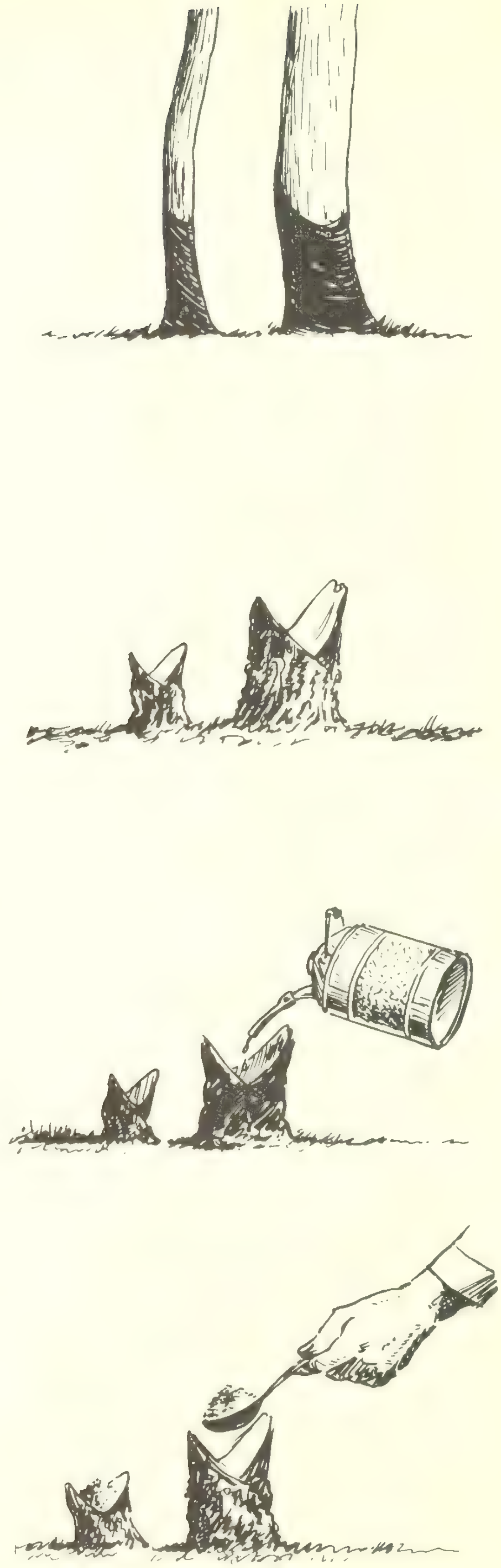
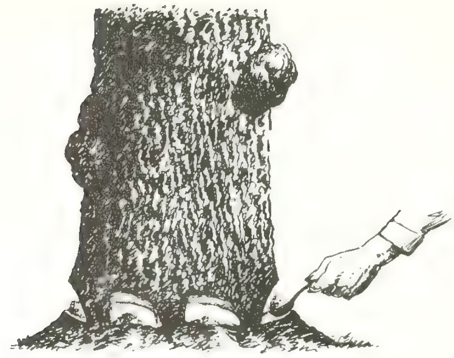


Figure 1.--Treatments used on trees smaller than 5 inches in diameter.

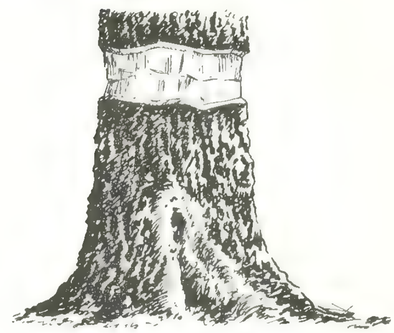
Treatment V

Ammate crystals were placed in cups made with an ax in the base of the tree.



Treatment VI

Control. A section of the bark was removed around the tree and no silvicide was applied.

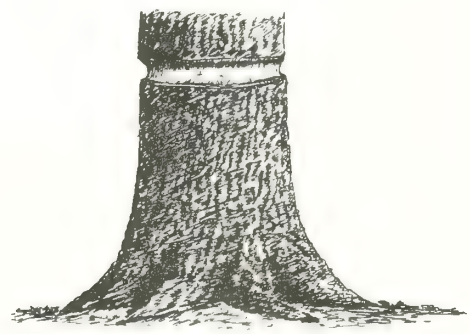


Treatment VII

Control. A complete girdle was made with a girdling machine and no silvicide was applied.

Treatment XI

Silvicide was applied in the girdle.



Treatments VIII through X

Frills, made by hacking downward with an ax, were filled with the silvicide.

Figure 2.--Treatments used on trees larger than 5 inches in diameter.

RESULTS

An analysis of variance showed a significant difference in sprouting on the two blocks. In general, sprouting was more profuse on Block B than on Block A. Since Block A is relatively flat and 2,500 feet in elevation, while Block B is steep with a northeast aspect and is 3,000 feet in elevation, several factors are probably involved in this block difference, such as elevation, slope, aspect, soil, and precipitation. Because the study was established over a period extending from March 9 to May 9, some of the variation may have been caused by change of season.

Results were measured in terms of percent of crown kill, number of sprouts, length of tallest sprout, and total length of sprouts. In discussions of sprout results in this report, only the number of sprouts will be used, since the treatments that resulted in the lowest number of sprouts per tree also gave the lowest values per tree for the other two measurements of sprout results.

In a discussion of hardwood control, it would be very desirable to know just what constitutes satisfactory or acceptable results. Complete crown kill and sprout control is of course desirable, but very seldom can be obtained in a reasonable length of time. What limits, then, are acceptable? Any line that might be drawn would be at least partly arbitrary.

Another approach would be to determine at what point a treated tree is no longer competing seriously with the desirable trees in the stand, or with reproduction. A tree crown that is 75- or 80-percent killed should no longer present any serious competition with surrounding trees; neither should a few weak sprouts be a serious problem. In view of these limits, any treatment that kills 75 to 80 percent of the treated canopy and prevents heavy sprouting would be considered effective, or satisfactory.

Satisfactory crown kill does not necessarily mean satisfactory sprout control, and vice versa. Crown kill and sprout growth results should each be considered in view of the other.

In this report, percent crown kill means an average percent crown kill for the entire group of trees in the category. For instance, an average crown kill of 50 percent may include trees with no crown kill to trees with 100-percent crown kill. In table 2, however, the percent crown kill is further broken down into percent of trees with total crown kill and an average percent of crown kill for the remainder. The table also shows the total average percent of crown kill and the average number of sprouts. Table 3 gives the sprouting results for the stump treatments on trees in the small-size group.

Small-Size Groups (0.6 to 4.9 Inches in Diameter)

Oak.--Treatment I (basal spray, 2, 4, 5-T in oil) gave good results (74-percent crown kill and 4 sprouts per tree). Treatment IV (stumps, Ammate crystals) gave very good sprout control.

Hickory.--The basal spray treatment did not give satisfactory results for hickory (56-percent crown kill). Treatment III (stumps, 2, 4, 5-T in oil) gave the best sprout control of the other three treatments.

Table 2.--Treatment results by species and size groups

SMALL-SIZE GROUP (0.6 to 4.9 INCHES IN DIAMETER)

Species	Treatment	Average percent crown kill	Percent of trees with total crown kill	Average percent crown dead, remainder	Average number of sprouts
Oak	I	74	72	19	4
Hickory	I	56	53	12	2
Red maple	I	81	72	31	4
Sourwood	I	20	11	12	0.4
Rhododendron	I	22	15	15	4
Laurel	I	89	70	65	.4
MEDIUM-SIZE GROUP (5.0 TO 11.9 INCHES IN DIAMETER)					
Oak	V	100	100	--	0
	VI	92	83	65	38
	VII	96	85	78	12
	VIII	87	70	59	14
	IX	88	80	42	28
	X	100	100	--	7
	XI	98	90	80	12
Hickory	V	43	30	19	1
	VI	86	68	56	10
	VII	67	59	41	8
	VIII	95	90	60	8
	IX	100	100	--	11
	X	100	100	--	2
	XI	92	75	80	6
Red maple	V	51	29	33	9
	VI	62	20	54	28
	VII	55	0	55	37
	VIII	57	30	40	35
	IX	61	26	49	28
	X	66	32	53	35
	XI	53	10	49	21
Sourwood	V	96	95	30	3
	VI	59	30	59	25
	VII	61	15	55	21
	VIII	62	28	51	16
	IX	67	26	56	25
	X	93	84	73	24
	XI	54	17	45	14
LARGE-SIZE GROUP (12.0 INCHES AND LARGER IN DIAMETER)					
Oak	V	91	85	47	0
	VI	96	90	60	2
	VII	99	95	80	5
	VIII	100	100	--	14
	IX	89	80	47	5
	X	100	100	--	1
	XI	92	80	62	5
Hickory	V	30	10	27	1
	VI	94	80	76	3
	VII	86	80	39	1
	VIII	87	60	72	1
	IX	96	84	82	0.4
	X	100	100	--	6
	XI	60	45	29	2

Table 3.--Average number sprouts for stump treatments on small trees (0.6 to 4.9 inches in diameter)

Treatment	Oak	Hickory	Red maple	Sourwood	Rhododendron	Laurel
II	10	7	19	12	34	33
III	9	3	11	6	8	4
IV	3	4	7	6	14	46

Red maple.--A basal spray of 2, 4, 5-T in oil gave good crown kill (81.5 percent) and low sprouting for red maple. None of the stump treatments was satisfactory.

Sourwood.--Ammate crystals on stumps is the only treatment that gave satisfactory results for sourwood in this size group.

Rhododendron.--Stumps treated with 2, 4, 5-T in oil gave very good sprout control for this species. None of the other treatments was satisfactory.

Laurel.--2, 4, 5-T in oil applied as a basal spray gave 89-percent crown kill and excellent sprout control for laurel. Stumps treated with 2, 4, 5-T in oil had an average of only 4 sprouts per stump.

Medium-Size Groups (5.0 to 11.9 Inches in Diameter)

Oak.--All treatments gave good crown kill, but treatments V (Ammate in cups) and X (ax-frills, 2, 4, 5-T in oil) gave best sprout control. There were no sprouts with treatment V and only 7 sprouts per tree for treatment X.

Hickory.--Treatments VIII (ax-frills, 2, 4, 5-T in water), IX (ax-frills, 2, 4, 5-T in water plus a wetting agent), X (ax-frills, 2, 4, 5-T in oil), and XI (machine-girdle, 2, 4, 5-T in oil) gave good crown kill for hickory, but treatment X (ax-frills, 2, 4, 5-T in oil) showed the best sprout control (2 sprouts per tree).

Red maple.--This species proved hard to kill by any of the treatments tested. Crown kill did not vary appreciably from about 55 percent and sprouting was profuse with all treatments.

Sourwood.--Treatment V (cups and Ammate) gave satisfactory results for this species (96-percent crown kill and 3 sprouts per tree). Treatment X (ax-frills, 2, 4, 5-T in oil) gave good crown kill, but did not control sprouting.

Desirable results on medium-size trees are illustrated in figure 3.

Large-Size Groups (12.0 Inches and Larger in Diameter)

Oak.--Good results were obtained with all treatments used, with the exception of heavy sprouting in treatments VII (machine-girdle) and VIII (ax-frills, 2, 4, 5-T in oil).

Figure 3.--These treated trees no longer compete with more desirable trees and seedlings.

Hickory.--Treatment IX (ax-frills, 2, 4, 5-T in H_2O + wetting agent) gave the best overall results for hickory. Ammate in cups (treatment V) gave very low crown kill (30 percent). There was a tendency for this species to bridge over the machine-girdle in treatments VII (machine-girdle--10-percent bridging) and XI (machine-girdle, 2, 4, 5-T in oil--20-percent bridging). This resulted in a lower crown kill for these two treatments (86 percent for treatment VII and 60 percent for treatment XI). The eradication of a few large cull and wolf trees releases many smaller trees, as illustrated in figure 4.

CONCLUSIONS

No one treatment is effective on all species over all size groups. Of the species tested, red maple and rhododendron are the most difficult to control. Listed below are the treatments recommended for each species and size group:

Species	Size	Treatment
Oak	Small	Stumps, Ammate crystals, 1 tbsp./2" d.b.h.
	Medium	Cups, Ammate crystals, 1 tbsp./cup, no.cups = $\frac{1}{2}$ d.b.h.; or ax-frills, 2, 4, 5-T in oil, 8 lbs. ahg.
	Large	Any good girdling treatment, silvicide not necessary.
Hickory	Small	Stumps, 2, 4, 5-T in oil, 20 lbs. ahg or Ammate crystals, 1 tbsp./2" d.b.h.
	Medium	Ax-frills, 2, 4, 5-T in oil, 8 lbs. ahg.
	Large	Ax-girdle (frill or notch) silvicide not necessary.
Red maple	Small	Basal spray, 2, 4, 5-T in oil, 20 lbs. ahg.
	Medium	No treatment was satisfactory.
Sourwood	Small	Stumps, Ammate crystals, 1 tbsp./2" d.b.h.
	Medium	Cups, Ammate crystals, 1 tbsp./cup, no.cups = $\frac{1}{2}$ d.b.h.
Rhododendron	---	Stumps, 2, 4, 5-T in oil, 20 lbs. ahg.
Laurel	---	2, 4, 5-T in oil, 20 lbs. ahg on stumps or as basal spray.

Figure 4.--The crowns of these large oak and hickory trees are beginning to break up three growing seasons after treatment. Sunlight can now reach the smaller trees and forest floor.

SUMMARY

In the spring of 1955, a study was established at the Bent Creek Experimental Forest to test several methods of hardwood control. Oaks, hickories, red maple, sourwood, rhododendron, and laurel were treated. Results were measured three growing seasons after treatment.

The treated trees were divided into three size groups: small (0.6 to 4.9 inches in diameter), medium (5.0 to 11.9 inches in diameter), and large (12.0 inches and larger in diameter). In the small-size group, best treatments were a 2, 4, 5-T in oil basal spray for red maple and laurel, stumps treated with 2, 4, 5-T in oil for hickories and rhododendron, and stumps treated with Ammate crystals for oaks and sourwood. In the medium-size group, Ammate in cups was best for oaks and sourwood, ax-frills treated with 2, 4, 5-T was best for hickories, and none of the treatments was satisfactory for red maple. Oaks and hickories in the large-size group were successfully killed by girdling alone. However, the hickories tended to bridge over the machine-girdle, but did not bridge over the notch-girdle made with an ax.

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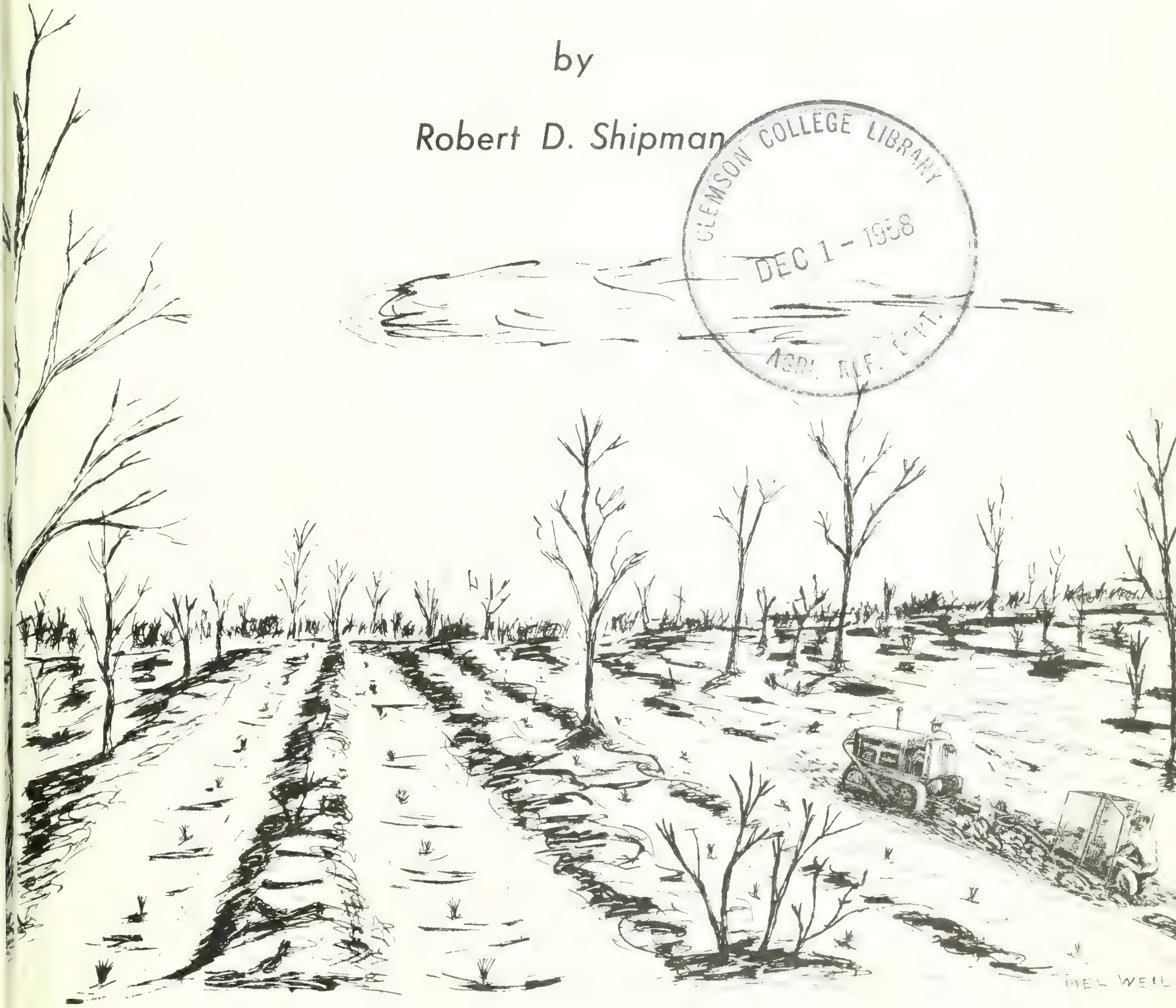
Agriculture--Asheville

Station Paper No. 96 September 1958

Planting Pine in the Carolina Sandhills

by

Robert D. Shipman



U. S. DEPARTMENT OF AGRICULTURE - FOREST SERVICE

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ERRATUM

In Station Paper 96, "Planting Pine in the Carolina Sandhills," by Robert D. Shipman, the percent survival in the headings of tables 3 and 4 on pages 12 and 13 and in the tabulation at the middle of page 13 should be footnoted to read:

> "First-year survival counts were taken only on seedlings of good and superior vigor--the surviving seedlings that can be expected to begin active height growth 2 to 4 years after planting. If seedlings of poor and fair vigor had been counted, the percent survival would have been considerably higher."

ACKNOWLEDGMENTS

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PLANTING PINE IN THE CAROLINA SANDHILLS

by

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INTRODUCTION

The man who is going to plant pine in the Sandhills will inevitably ask himself, "When shall I plant? What species will I choose? How do I plant them? What are the chances for survival?"

These have been some of the knotty questions asked by foresters and landowners for many years in the adverse Sandhill sites. Now, after 4 years of intensive regeneration research, we have some answers, many of them partial, but with helpful leads. Most of our research has been with longleaf pine, the species most difficult to establish on dry, Sandhill areas. Successful planting methods developed for this species will, in our opinion, apply in general to the more easily established species. The most urgent problem in the Sandhills is survival--how to bring the area into production of forest crops at reasonable cost.

The Sandhills of North and South Carolina and Georgia once supported good stands of longleaf pine with some hardwoods and loblolly pine on the stream terraces. The original pine forest vanished and no one much cared--until recently. Now it is hard to replace because decades of fire and leaching have kept soil fertility low, and a dense understory of small scrub oaks and wiregrass compete with pine seedlings. Insufficient seed trees remain to restock the area adequately by natural means.

The earliest effort at rehabilitating these seemingly worthless lands was begun in 1936 by the South Carolina State Commission of Forestry. The first plantings were on old fields, which are the better sites, and by 1946 the Commission turned its attention to clearing scrub oak lands for planting. Slash and loblolly plantations were reasonably successful, but longleaf failed. In July 1948, a series of eight plots was established on the Sand Hills Forest by the Santee Research Center of the Southeastern Forest Experiment Station. On these plots, chemical methods of controlling scrub oak were tested. In 1949, Keith W. Dorman, of the Southeastern Station, prepared a "Problem Analysis of Forest Regeneration in the Sandhills of the Carolinas and Georgia." This analysis was an important step in defining regeneration problems in the Sandhills and largely formed the basis of the later and more intense research program. Then in 1952, with the expanded emphasis on forest regeneration, the Santee Research Center enlarged its Sandhills research efforts. In the same year, the Atomic Energy Commission began an extensive large-scale regeneration program in South Carolina. The AEC annually plants over 9 million seedlings on abandoned fields within the Sandhill region.

This paper gives 4 years' results of studies attempting to find ways of establishing longleaf more successfully. We know quite a lot about planting slash pine in the Sandhills, since many existing slash pine plantations are now more than 20 years old. With longleaf, the situation is quite different; extensive plantations did not exist, mainly because we did not know how to plant this species so that it would survive the critical early years. The studies reported here show that longleaf can be planted successfully if the site is properly prepared and only high-quality nursery stock is used. New information on other species also has been developed which will be useful in future planting programs.

BASIC FACTS ON THE SANDHILLS

Size and Location

The Sandhill region of the Carolinas and Georgia is a nearly continuous, irregular, narrow strip 10 to 40 miles in width and 420 miles long. The total acreage is nearly 8 million acres, of which more than 3 million are coarse deep sands suitable only for the production of forest crops. Of these deep sands, approximately 1,500,000 acres are in South Carolina, 820,000 acres in Georgia, and 680,000 acres in North Carolina. Following the edge of the Piedmont, the Sandhills form the upper part of the Coastal Plain, extending southwestward from Sanford, North Carolina, to Columbus, Georgia. The area is divided into five parts on the basis of underlying geologic formations (2). These subdivisions closely parallel the severity of site conditions. The Congaree Sandhills and similar areas of the Georgia Fall-line Hills are the most northern and southern areas respectively. Extremely deep sands, long gentle slopes and rounded summits, make these the most difficult areas. The Richland Red Hills and High Hills of Santee, located in central South Carolina, rank as the best sites; the Aiken Plateau area may be classified as intermediate between the most difficult and the best sites (fig. 1).

Soils and Soil Moisture

Soil and its relation to precipitation play major roles in limiting first-year seedling survival in the Sandhills. The principal soils are the Norfolk, Ruston, and Orangeburg series, which differ mainly in the color and nature of the subsoil. There are also small areas of Marlboro, Bradley, Hoffman, and other series. All are exceptionally well-drained,[1] both in the surface and subsoil. The materials for these series were deposited by the ocean during several periods of inundation. They are characterized by light-gray or grayish-yellow sand or loamy sand surface soils, and predominantly yellow, friable sandy clay or sand subsoils (17). Elevations throughout the Sandhills generally range from 100 to 600 feet above sea level. Drainage is rapid and the soils occur on broad flat ridges as interstream areas, or on land which

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1/ Dorman, K. W. Problem Analysis of Forest Regeneration in the Sandhills of the Carolinas and Georgia. Office report, U. S. Forest Serv. Southeast. Forest Expt. Sta. 1949. Revised 1956 by R. D. Shipman.

is steeply sloping or hilly. As a result of this drainage pattern, leaching of plant nutrients is rapid, the soils are strongly acid in reaction, and organic matter is inherently low (19). These conditions have a direct bearing on soil fertility, soil texture, and the all-important soil moisture relationships (8).

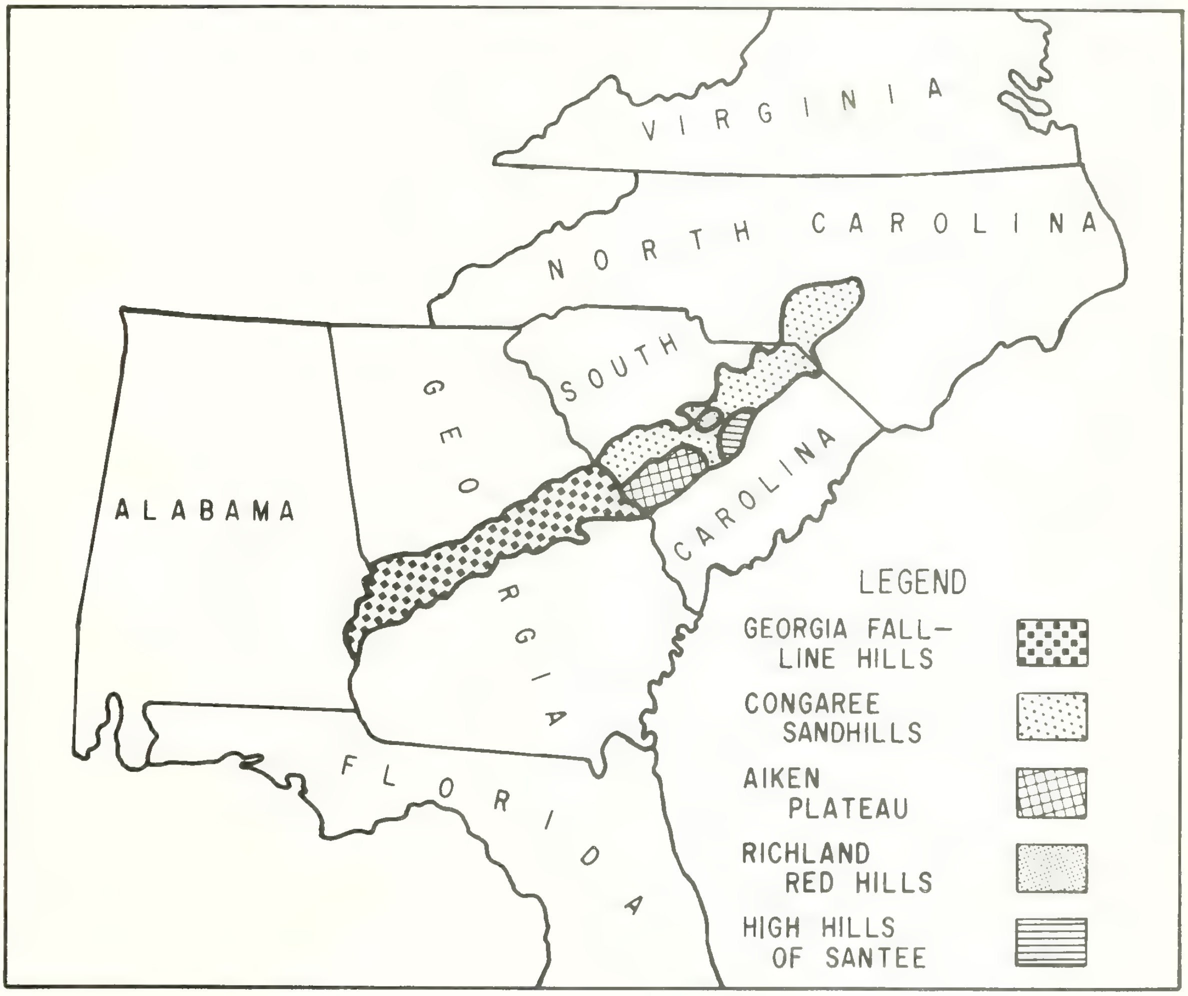

Figure 1.--Subdivisions of the Sandhills.

Drought is the principal cause of seedling mortality in the Sandhills. Despite the fact that rainfall averages over 45 inches a year, the sandy soils do not retain this moisture. For this reason, the Sandhills have been aptly called "deserts in the rain"--a land of coarse, deep sands subject to extremes in growing season temperature and moisture availability. Frequently rain does not occur for a 3- to 4-week interval during the critical growing season; moreover, within 3 days after a summer rain, drought conditions may prevail. Desert-like plants such as cactus, lichens, and wiregrass (Aristida stricta) indicate the extremely dry conditions. Exceedlingly high surface soil temperatures intensify the already rapid soil-moisture evaporation. As an example of desert conditions, the leaves of turkey oak (Quercus laevis) are oriented edgewise, and the cotyledons of longleaf seedlings stand upright to avoid reflected heat.

Present Cover Condition

After the original timber was cut, uncontrolled fire and cultivation reduced the forest area to its present state--scattered longleaf with an understory of scrub oak, largely turkey oak. The abundance of turkey oak is closely related to absence of fire, but even with fire turkey oak holds on in a repressed condition through its well-known habit of sprouting. It is present over vast areas and will increase in size and dominance with protection from fire (fig. 2). Dense stands of turkey oak may exceed 3,400 or more stems per acre ranging from $\frac{1}{2}$ to 6 inches in diameter (11). On the better or more moist sites, turkey oak gives way to bluejack oak (Quercus brevifolia) and blackjack oak (Quercus marilandica). The best sites support such species as sand post oak (Quercus stellata var. margaretta), post oak (Quercus stellata), hickories (Carya spp.) and white oak (Quercus alba). The lesser vegetation on Sandhill lands consists primarily of wiregrass and broomsedge (Andropogon scoparius), which also compete with planted seedlings for soil moisture and nutrients. The Sandhills include large acreages of old fields with varying amounts of grass and weed cover. For planting purposes these are classed as the better sites.

Figure 2.--A typical scrub oak planting site in the South Carolina Sandhills.

CHOOSING THE RIGHT SPECIES

One of the first problems facing the prospective Sandhill planter is the choice of species. For the past 25 years the major planting has been restricted to three southern pines. The pines most easily established on these sites are slash pine (*Pinus elliottii*) and loblolly pine (*Pinus taeda*). Longleaf pine (*Pinus palustris*), despite the fact that it formed the original forest, has been difficult to re-establish until recently.

Whether the objective is production of pulpwood-size trees or sawtimber, it is important to select the species best adapted to the local soil and climatic pattern. Susceptibility to such factors as drought, fire, disease, insects, wind, and animal damage play a vital role (18). Admittedly there are schools of thought on species choice; but the writer's experience leads him to accept longleaf pine as one of the best species to plant in the Sandhills because its superiority in withstanding these adverse conditions over the long haul may be of greater significance for timber production than early-growth superiority of certain other species.

Species Adaptability and Early Growth

For information on establishment and past performance of the most commonly planted species, we must look to the earliest plantings on State lands, which date from the 1930's. Slash pine did not occur in the original forest, and loblolly pine was generally confined to the moist sites along stream courses and first bottoms. On level hilltops, where the sand was deep, longleaf pine was found in rather open stands with trees up to 18 inches in diameter. On lower slopes, or where roots could make contact with water-retaining clay or red sand layers, the trunks were about 3 feet in diameter (1).

Due to its characteristic delay in emerging from the grass, longleaf pine may be 2 to 3 feet shorter than other species at early ages. Such a delay can be partly offset by removal of grass and weed competition at the time of planting. A comparison of early height and diameter growth between longleaf and slash pine planted on sites of similar quality shows an early height difference in favor of slash pine (fig. 3). On the other hand, its relative freedom from infection by southern fusiform rust (*Cronartium fusiforme*), and its remarkable resistance to fire definitely favor longleaf. There has been some localized damage from brown spot needle disease, caused by *Scirrhia acicola*, and a question remains whether this infection originated from the nursery. All things considered, longleaf is one of the preferred species to plant in the Sandhills (fig. 4).

However, although it is generally assumed that deep sands are longleaf sites, most landowners plant slash pine because it survives better. In spite of the fact that most of the Sandhills area is outside of the slash pine range, plantations dating from the 1930's have grown faster than plantations of the native longleaf on the better sites (fig. 5).

Figure 3. --Comparison of early height and diameter growth of longleaf and slash pines after 5 growing seasons. Both species were planted in old fields of similar soil type and spacing, Savannah River Project, S. C. Above, longleaf, average height 7.7 feet, average diameter 2.75 inches. Below, slash, average height 9.7 feet, average diameter 3.10 inches.

Figure 4.--A 19-year-old longleaf pine plantation on an old-field site, Sand Hills State Forest, S. C.

Figure 5.--Pulpwood marking on a 17-year old slash pine plantation, Sand Hills State Forest, S. C.

It should be pointed out that many of these slash pine plantations are infected with southern fusiform rust, but generally not so severely as in many localities outside the Sandhills where a great deal of slash pine has been planted. Some stands are infected by the root rot fungus (Fomes annosus), especially on the heavier soils.

Loblolly pine is particularly susceptible to attack from tip moth (Rhyacionia frustrana) in young plantations. Such infestation generally declines as the stands mature, but often results in delayed growth and poor form. There is some evidence that loblolly pine may be "off-site" on the majority of Sandhill areas. On the better old-field sites, many stands of loblolly are heavily infected with southern fusiform cankers, especially on the branches.

Since information was still insufficient to make firm recommendations regarding the best species to plant, a test was begun in 1955 to determine the early survival and adaptability of ten different coniferous species planted on cleared shrub oak areas of the Manchester State Forest, S. C. (table 1).

Table 1.--Survival of coniferous species planted on cleared Sandhill sites

Species	Seed source	1955 planting	1956 planting	Average
		- - Percent survival - -		
Redcedar (*Juniperus virginiana*)	N. Carolina	99	87	93
Virginia pine (*Pinus virginiana*)	Tennessee	96	87	91
Loblolly pine (*Pinus taeda*)	S. Carolina	94	87	90
Shortleaf pine (*Pinus echinata*)	N. Carolina	89	87	88
Slash pine (*Pinus elliottii*)	S. Carolina	95	77	86
Jack pine[1/] (*Pinus banksiana*)	Michigan	--	80	--
Longleaf pine (*Pinus palustris*)	S. Carolina	81	65	73
Pond pine (*Pinus serotina*)	N. Carolina	77	68	72
Spruce pine (*Pinus glabra*)	S. Carolina	71	--	--
Lodgepole pine (*Pinus contorta*)	Oregon	--	47	--

1/ 2-0 planting stock.

Although it is too soon to make valid comparisons of early growth, survival and vigor were satisfactory with all species except lodgepole pine. Excessive crookedness and side branching were particularly marked among the pond, Virginia, shortleaf, loblolly, spruce, jack, and lodgepole pines. Best early form was exhibited by slash pine and redcedar.

Pond pine, characteristically a wet-site species, showed a good early response to a dry site despite its poor form. The survival of lodgepole and jack pines is of special interest, since these species are considerably beyond their natural range. The high survival and vigor of redcedar points to a possibility of Christmas-tree production.

The future survival and growth of these seedlings will further test their adaptability to Sandhill soils. This initial test suggests that redcedar, slash, longleaf, shortleaf, and possibly Virginia pine, have most promise for future planting, with loblolly restricted to the better sites on stream terraces (16). More extensive use of longleaf planting stock is anticipated, in view of the recent improvements in planting methods. Other species, including hybrids, should be tested.

The soil and site relationships of the important Sandhill species will be investigated more fully in the future. A plantation yield study started in 1957 will provide needed information on the adaptability of various species to different sites (see footnote 1).

NURSERY TREATMENTS AND THEIR EFFECT UPON LONGLEAF SURVIVAL

The production of high quality and drought-hardy planting stock is of prime importance to successful plantation establishment on dry sites. Newly planted seedlings must be able to withstand the rigorous drought and sudden freezes of the area. Good planting practices begin in the nursery with the production of the best morphological and physiological grades of planting stock. Santee Research Center studies during the past 4 years have given high priority to testing the effect of various nursery treatments upon early survival of longleaf pine.[2]

Seed Source

As part of the regeneration program, a small test on the effect of geographic seed source on survival was made. Seed was collected from three different seed sources: (1) upper Coastal Plain, N. C., Bladen County; (2) upper Coastal Plain, S. C., Aiken, Chesterfield, Richland, and Sumter Counties; (3) lower Coastal Plain, S. C., Berkeley, Horry and Jasper Counties. Eight hundred longleaf pine seedlings were raised from seed of each source. After the first year, survival in Group 1 was 91 percent, Group 2 was 83 percent and Group 3 was 78 percent. Seedlings from the more northerly seed source had a higher percentage of survival, but many years must elapse before the full effect of seed source becomes apparent.

2/ Most trials were conducted in cooperation with Dr. T. E. Maki, School of Forestry, North Carolina State College. Seedlings were outplanted on lands of the South Carolina State Commission of Forestry and the Savannah River Project of the Atomic Energy Commission, South Carolina.

Season of Sowing

In the South Carolina Sandhills, slash, loblolly, and longleaf pine seed is most often sown in the nursery during late February and March. The principal reason for spring sowing is to reduce the risk of late winter freezes and losses of seed to migratory birds. These factors have caused appreciable losses in nurseries in this locality. Occasionally, longleaf and other species are sown in the fall (October and November). Larger stock results from fall sowing than from spring sowing in Sandhill nurseries (fig. 6).

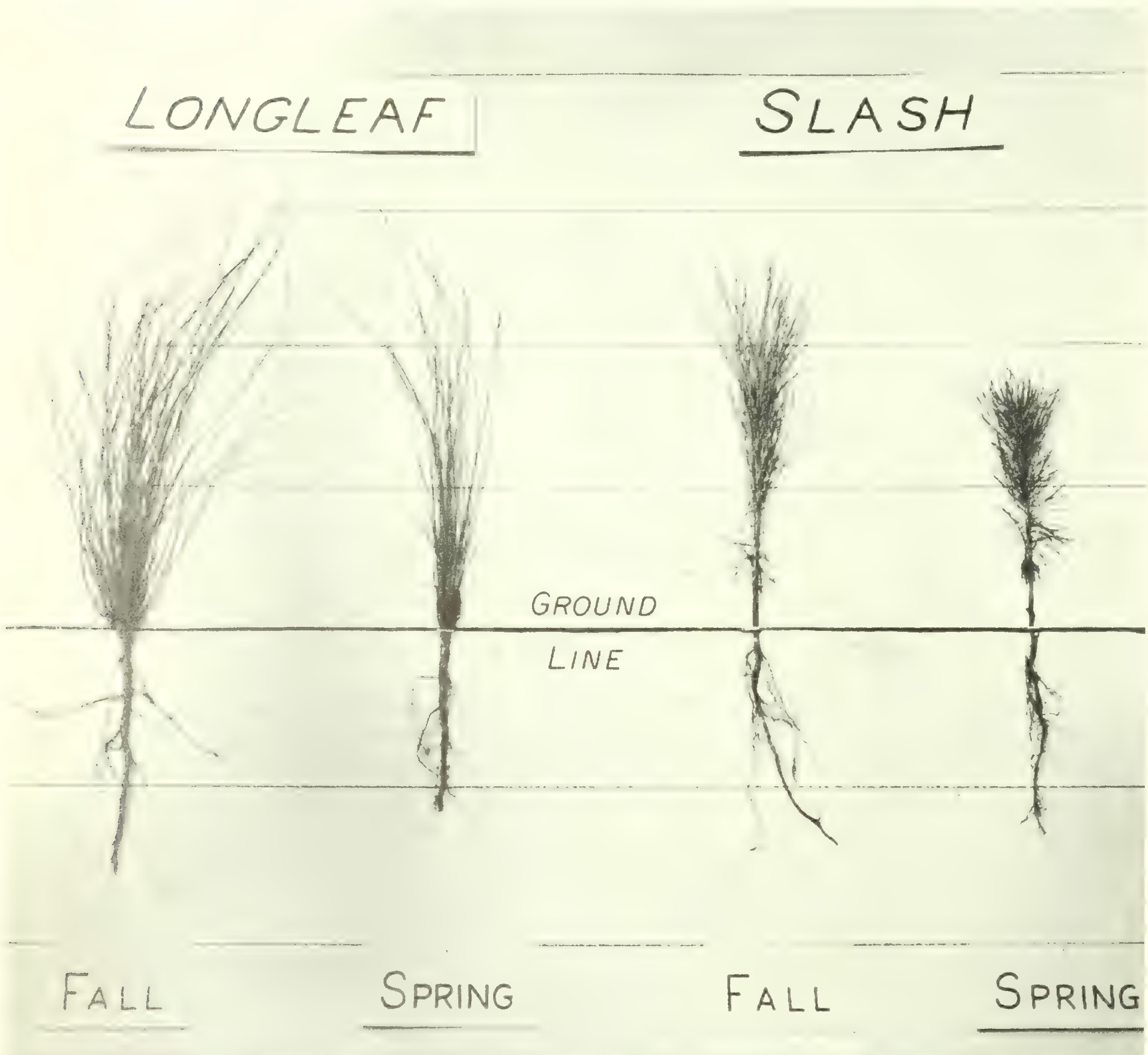

Figure 6.--Longleaf and slash pine seedling size as affected by season of sowing in the nursery. Fall-sown (October) and spring-sown (March). Horizontal lines are 4 inches apart. Horace Tilghman Nursery, S.C.

Our tests showed that under all site conditions fall-sown longleaf nursery stock survives better than spring-sown (table 2). Maximum survival, 96 percent, was obtained with fall-sown stock planted on old-field, furrowed sites. The poorest survival, 55 percent, occurred on old fields with spring-sown stock.

Table 2.--Effect of season of sowing in nursery upon first-year longleaf survival on various planting sites.

Planting site	Fall-sown (November)	Spring-sown (March)
	- - Percent survival - -	
Scrub oak, furrowed	84	79
Scrub oak, furrowed poisoned	71	60
Scrub oak, cleared furrowed	78	76
Scrub oak, cleared	81	77
Old field, furrowed	96	87
Old field	62	55
Mean for all sites	79	72

Seedbed Density

The objective of regulating density of seedling stands in nursery beds is to produce the maximum number of top quality, plantable seedlings at lifting time. Sowing too much seed per bed (high density) merely intensifies competition among the seedlings; sowing too little seed per bed may produce seedlings too large to plant and may not fully utilize the soil capacity. The number of seedlings to be grown per square foot should be closely related to the true basis of good nursery economics--high field survival.

Two separate investigations to determine the relation of seedbed density to longleaf survival were established in 1952 and 1953 (6). All seedlings were grown at the Clayton Nursery, N. C., in cooperation with the Division of Forestry, N. C. State Department of Conservation and Development and the North Carolina State College, School of Forestry. The nursery beds were thinned in mid-June to 10, 20, and 40 seedlings per square foot and half were root-pruned in July. The lower bed densities and half of the high density seedlings were given periodic dosages of nitrogen, phosphorus, and potassium during the growing season.

Three planting trials of seedlings were made in: (1) old, abandoned fields with a 7-8 year "rough"; (2) deep (10-inch) furrowed scrub oak; and (3) scrub oak poisoned in advance of planting. During both investigations the summer months were some of the hottest on record and rainfall was deficient at all locations by October. Under all site conditions, seedlings grown at the lower bed densities showed significantly better survival and vigor than those grown at the highest density (table 3 and fig. 7).

Table 3.--First-year longleaf pine survival as affected by nursery seedbed density when field planted under three different site conditions
(In percent survival)

Treatment	Number of seedlings per square foot		
	10 (low)	20 (medium)	40 (high)
Old field	29.3	23.1	12.3
Deep (10-inch furrows)	51.8	45.8	37.7
Poisoned scrub oak	36.7	37.1	20.8

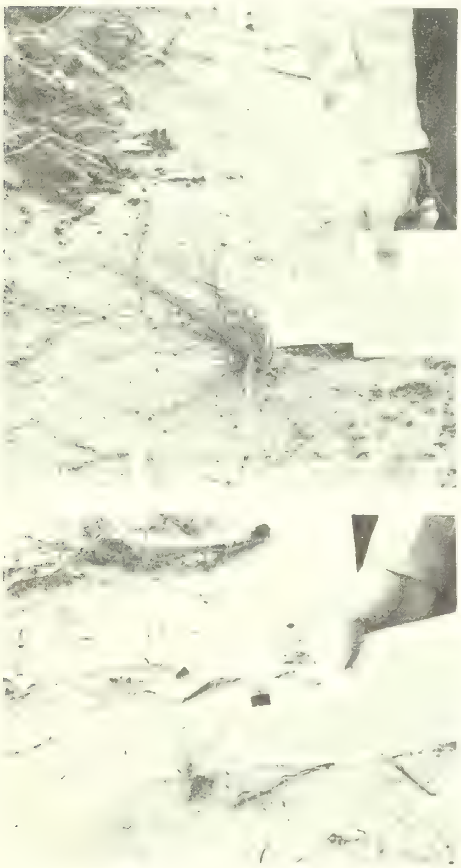

Figure 7.--Longleaf seedlings taken from nursery beds of different densities and planted on deeply furrowed scrub oak areas. Savannah River Project, S.C. Above, large and vigorous seedlings from medium density beds (20 per square foot). Below, smaller less vigorous seedlings taken from high bed densities of 40 per square foot.

Root Pruning

Normally, seedlings in large nurseries are lifted by tractor-drawn lifters which undercut the seedling beds, thus pruning the roots to a length of 7 or 8 inches. This same equipment is often used to root prune during the growing season. The aim of additional root pruning during the active growing season is to create a more fibrous system, or to encourage the development of a large number of small lateral rootlets. In our tests root pruning in mid-season (July) of the first year in the nursery beds definitely improved longleaf seedling survival (6). The greatest response to pruning occurred with seedlings grown at high bed densities. Even at low densities, however, pruned seedlings survived better and were more vigorous than unpruned seedlings (table 4). These differences occurred despite the fact that all seedlings were outplanted under the best site preparation treatment (deep furrows).

Fertilization

Fertilization of southern pine seedlings in the nursery has varied effects upon the size and physiological quality of planting stock. The effects of inorganic fertilizers are

Table 4.--First-year survival of pruned and unpruned longleaf seedlings outplanted from three seedbed densities
(In percent survival)

Treatment	Number of seedlings per square foot [1]		
	10 (low)	20 (medium)	40 (high)
Pruned	98.3	96.2	88.6
Unpruned	93.7	92.7	79.1

1/ All fertilized, spring-sown stock.

closely associated with watering practice and soil characteristics. Some chemical elements are harmful; others are decidedly favorable to production of quality seedlings. As with bed densities, the object of fertilization is to produce seedlings with internal and external characteristics that will enable them to withstand the rigors of climate after planting.

Although our nursery fertilization tests have not been intensive, they serve to indicate the importance of various controlled fertilizer applications. The addition of fertilizer during the growing season at the rate of 200 pounds ammonium nitrate (35 percent N), 200 pounds potassium chloride (48-60 percent K_20), and 600 pounds superphospate (16-47 percent P_20_5) per acre had a highly significant favorable effect on survival of longleaf seedlings (6).

The effect of supplemental fertilization of longleaf seedlings was most marked on seedlings grown at high bed densities of 40 per square foot. In a test which included 300 seedlings for each treatment, first-year survival of fertilized longleaf seedlings was 4.4 percent better than that of unfertilized seedlings:

Seedlings per square foot of seedbed (Number)	First-year survival Fertilized (Percent)	First-year survival Not fertilized (Percent)
40 (high)	23.6	19.2

Effect of Soil Texture on Seedling Roots

Two exploratory studies indicated that the successful planting of longleaf pine may be related in part to the amount and position of lateral roots of seedlings. It is apparent that the most fibrous portion of the root system should be developed at a depth where maximum soil moisture is available. On sandy areas, this is probably the bottom half of the planting hole. One of the most promising methods of developing a more fibrous root system for longleaf pine is to select areas of proper soil textures for nursery sites. This possibility of modifying the root system was explored in a cooperative investigation with the West Virginia Pulp and Paper Company [3] in South Carolina.

3/ At the Westvaco Experimental Forest, Georgetown, S. C.

In our initial test, longleaf pine seedlings of 1-0 stock were planted in each of several 10-inch soil profiles varying in texture from sand to sandy clay. One-year results indicate that both the number and position of lateral roots are strongly influenced by soil profiles. For example, seedlings in a sandy soil had an average of 13.6 lateral roots at a 7-inch depth, while those in a sandy clay had an average of only 3.6 lateral roots at the same depth. In soils of intermediate textures the average number of lateral roots was between those two extremes (15).

Following these early leads, a second experiment was designed to compare early survival of outplanted seedlings grown on various nursery soil profiles. Soils of four different profiles were located at a small nursery on the Westvaco Experimental Forest, South Carolina. A mechanical analysis of each soil was made, with duplicate samples taken at 3 and 10 inch depths. On each of these soils, seed from a Sandhill source was sown in drills 3 inches apart in March 1955. By means of a sharpened spade, half of each bed was root pruned to a depth of 6 inches in early August 1955, and was lifted for planting in January. Some stock from each bed was reserved, and root counts were made (fig. 8). The seedlings were outplanted in January 1956 on a deep sand at the Manchester State Forest, in South Carolina. Trees were spaced approximately 6x6 feet and hand-planted by experienced planters.

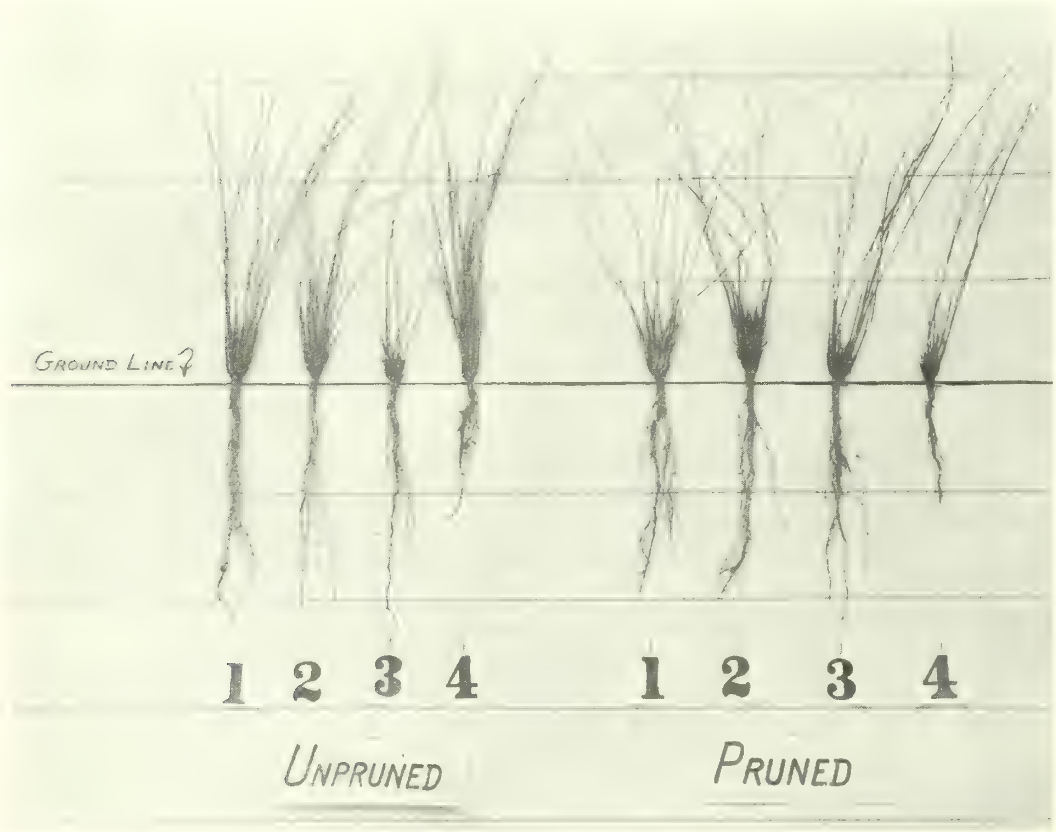

Figure 8.--Stem and root condition of the "average" longleaf seedling, roots pruned and unpruned, produced in four natural soil profiles in nursery beds of the Westvaco Experimental Forest. Distance between lines 4 inches. (1) Sandy loam over clay loam; (2) loamy sand over sandy clay loam; (3) sandy loam; (4) loam over clay loam.

Best survival was obtained on soils 1 and 3, which were predominately sandy loams with a high proportion of sand and low silt-plus-clay content (table 5). Poorest survival occurred on soils 2 and 4, which were mainly clay

Table 5.--Relationship between nursery soil characteristics and first-year longleaf pine survival

Soil profile number	Depth of measurement	Soil characteristics			First-year survival 2/
		Texture 1/	Sand content	Silt plus clay content	
	Inches	Class	Percent	Percent	Percent
1	3	Sandy loam	70	30	87
	10	Clay loam	44	56	
3	3	Sandy loam	76	24	82
	10	Sandy loam	72	28	
2	3	Loamy sand	84	16	74
	10	Sandy clay loam	67	33	
4	3	Loam	36	64	50
	10	Clay loam	38	62	

1/ Textural classification: Soil Survey Manual, U. S. Dept. Agr. Handbook No. 18, p. 209.

2/ Basis: 75 seedlings per treatment.

loams with a low sand and high silt-plus-clay content. No significant differences in survival were found between pruned and unpruned seedlings. Soils 1 and 3 also produced the greatest amount of foliage and lateral roots (table 6). The plotted values showed that soils 1 and 3 gave an average of 3.5 lateral roots at a 7-inch depth, while soils 2 and 4 produced an average of only 1.7 lateral roots at the same depth (fig. 9). Thus, quality of longleaf planting stock for planting on Sandhill sites is strongly related to nursery soil textures.

Table 6.--Relation between seedling and seedbed soil characteristics at the end of the first year

Soil profile number	Soil texture	Seedling characteristics				
		Average stem diameter	Average needle length	Average taproot length	Dry weight material produced	
					Foliage	Roots
	Class	Inches	Inches	Inches	Grams	Grams
1	Sandy loam to clay loam	0.34	11.4	7.2	26.3	18.6
3	Sandy loam	0.30	10.4	7.6	20.5	15.4
2	Loamy sand to sandy clay loam	0.29	10.6	6.6	19.7	12.2
4	Loam to clay loam	0.24	11.0	3.1	14.0	6.0

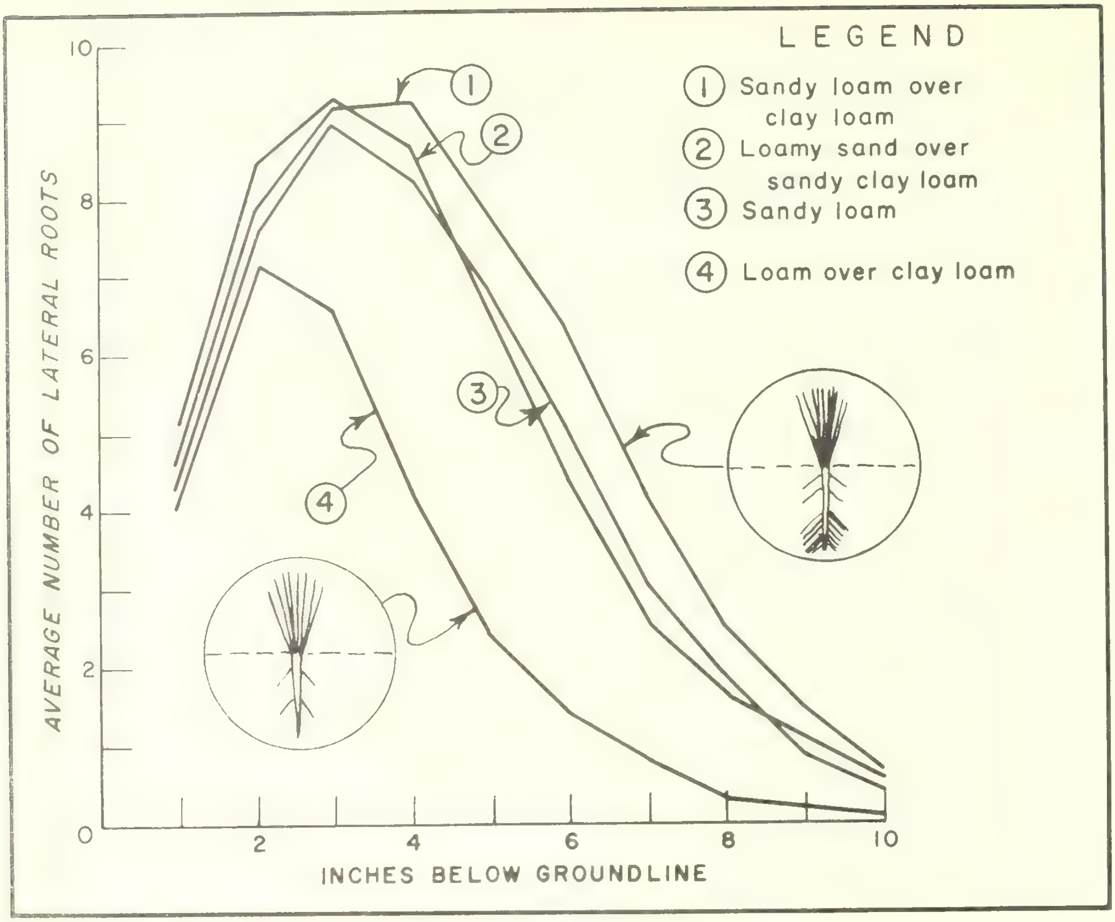

Figure 9.--Frequency of lateral roots of 1-0 longleaf pine at different depths when grown under natural soil profiles.

Seedling Grades

The grading of nursery stock is based primarily upon the capacity of seedlings to survive and grow after planting. According to Wakeley (18), grades of southern pine nursery stock can be judged mainly from their morphology or size. Recently, Wilde and Voigt (20) established analytical procedures for the determination of morphological and physiological characteristics of red pine and other coniferous seedlings. They analyzed 20 properties of stock which may also be useful in estimating quality of southern pine nursery stock. Until this procedure is tested locally, a good criterion for expected survival of nursery-run longleaf pine in the Sandhills is the general appearance, or morphological grade of seedlings.

The results obtained in one of our earliest studies, in cooperation with the Savannah River Project of the Atomic Energy Commission, indicated the practical implications of judging seedlings according to grade or size. Several of these trials have provided the Project Forester with basic information needed for "prescription planting," now being applied to old fields of the Savannah River Project.

Our earliest study of nursery stock grades involved the hand planting of 2,400 (1-0) longleaf seedlings from a local seed source at a 6x6-foot spacing on sandy loams and deep sands of the Savannah River Project in South Carolina.

Each plot compared seedlings of grades 1 and 2, foliage clipped and unclipped, and spring (March) versus winter (January) planting on the foregoing soil types. The longleaf seedlings were graded according to the following morphological specifications (18) at the Stuart Nursery in Louisiana, where all Savannah River Project stock is grown:

Grade	Usual height (Inches)	Thickness of stem at ground (Inches)	Needles	Winter buds
1	12 to 16	$\frac{1}{4}$ to $\frac{1}{2}$ or larger	Abundant. Almost all 3's and 2's	Usually present; usually with scales
2	8 to 15; 6 to 8 if stem and buds are good	At least 3/16	Moderately abundant; at least part in 3's or 2's	Usually present; usually without scales.

Grade 1 seedlings had significantly better survival than grade 2 seedlings on both soil types (table 7). Both grades of seedlings survived markedly better on sandy loam than on deep sand and survived better when planted in winter.

Table 7.--Second-year longleaf survival, as affected by seedling grade, soil type, and planting season

Seedling grade	Winter-planted		Spring-planted	
	Sandy loam 1/	Sand 2/	Sandy loam	Sand
	- - - - - - Percent survival - - - - - - -			
1	76	40	66	38
2	58	18	27	10

1/ 18 inches or less to clay layer.

2/ 36 inches or more to clay layer.

Clipping the foliage to 5 inches in length improved the survival of winter-planted grade 1 seedlings but reduced survival of spring-planted seedlings (table 8).

Table 8.--Second-year longleaf survival, as affected by seedling grade, foliage clipping, and planting season

Seedling grade	Winter-planted		Spring-planted	
	Foliage clipped [1/]	Foliage unclipped	Foliage clipped	Foliage unclipped
	- - - - - - - - Percent survival - - - - - - - -			
1	68	48	42	62
2	38	38	18	20

1/ To 5 inches in length.

The effect of seedling grade on the number of seedlings beginning early height growth was quite marked; 41 percent of the grade 1 but only 16 percent of the grade 2 seedlings were beginning active height growth at the termination of the third growing season (fig. 10).

A second test of seedling grades in relation to early survival and growth was made in cooperation with the S. C. State Commission of Forestry on State Forest lands. In this test roots were pruned to 3, 5, and 7 inches at planting time. A total of 4,800 longleaf pine seedlings (1-0) from a local seed source were outplanted in randomized blocks on cleared scrub oak areas of the Sandhills. The effect of planting season was similar to that in the first test. Pruning the roots to 3 inches at the time of planting was obviously too drastic, especially in the spring. Seedlings with roots pruned to 5 and 7 inches survived better with only small differences between treatments (table 9). Furthermore, root pruning to 3 or 5 inches in the spring resulted in much lower survival for the larger (grade 1) seedlings.

Table 9.--Effect of longleaf seedling grade, root pruning and season of planting on first-year survival
(In percent survival)

Seedling grade	Winter-planted and root-pruned to--			Spring-planted and root-pruned to--		
	3 in.	5 in.	7 in.	3 in.	5 in.	7 in.
1	62	82	74	34	58	64
2	59	71	71	46	67	63

Figure 10.--Longleaf seedlings 3 years after planting on old-field sites, Savannah River Project. Above, grade 2 seedlings, spring planted. Below, grade 1 seedlings, winter-planted.

In determining that larger seedlings generally survive better than smaller seedlings a further question arose regarding the later performance of the high-grade seedling; that is, would the larger seedlings continue to grow better than the smaller seedlings after the first year in the field? To partly answer this question, an investigation was begun in 1952.

Three species of southern pine seedlings--loblolly, slash, and longleaf--from a similar seed source were grown at the Horace Tilghman Nursery in South Carolina. The best seedlings in the nursery beds were selected on the basis of the following ratios: the largest 1 in 3,000 of longleaf, and the largest 1 in 10,000 of slash and loblolly. These were outplanted at 6x6-foot spacing with an equal number of "bed-run" seedlings of the same seed source. The select longleaf seedlings ranged upwards from $\frac{1}{2}$ inch in stem diameter; the select loblolly and slash pine seedlings were at least 3/16 inch in stem diameter and 8 and 9 inches in height (figures 11 and 12).

Figure 11.--At right, a superior longleaf seedling $\frac{1}{2}$ inch in stem diameter, the best individual selected from 3,000 in beds. At left, a bed-run longleaf seedling $\frac{1}{4}$ inch in stem diameter.

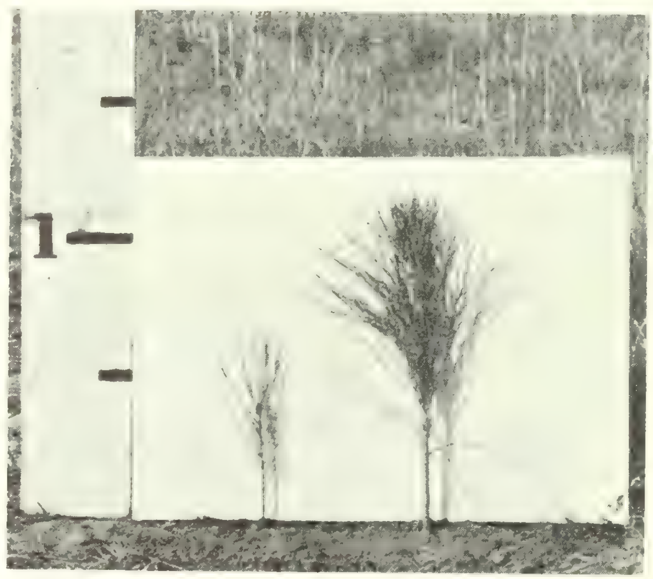

Figure 12.--At right, a superior slash pine seedling 3/16 inch in stem diameter, 9 inches tall, the best individual selected from 10,000 in beds. At left, bed-run slash pine seedling 1/16 inch in diameter, 5 inches tall.

After 4 years in the field the height differences have changed only slightly (table 10). The height growth of both classes of slash pine seedlings continues to be much better than that of either longleaf or loblolly.

Table 10.--Average height of selected bed-run and superior seedlings after four growing seasons
(In inches)

Species	1-year-old seedlings		4-year-old seedlings	
	Bed-run	Superior	Bed-run	Superior
Longleaf	--	--	24.2	35.4
Loblolly	4.0	8.4	51.4	63.7
Slash	4.0	8.4	105.2	110.3

However, a comparison of growth and basal area indicated a better volume on select trees. Basal area of each tree was obtained approximately 2 inches above the ground-line. The results showed that the basal area of longleaf and loblolly select trees was nearly twice that of bed-run trees (table 11). A similar relationship existed for slash pine although the difference in basal area was less marked.

Table 11.--Basal area and volume of bed-run and select seedlings after four growing seasons (1952-1956)

Species	Average basal area per tree 1/		Average volume per acre 2/	
	Bed-run	Select	Bed-run	Select
	- - Square feet - -		- - Cubic feet - -	
Longleaf	.0107	.0140	13.1	25.0
Loblolly	.0123	.0197	31.8	63.3
Slash	.0369	.0428	195.8	237.9

1/ 2 inches above groundline.

2/ 6x6-foot spacing, or 1,210 trees per acre.

Thus, in terms of volume, the larger or select nursery trees continue to express their dominance (16). It is too early to tell whether this dominance will be maintained through the life of the plantation. However, this investigation shows the desirability of producing large nursery stock, not only because such stock survives better, but also because large seedlings may reach merchantable size sooner.

Age of Stock

Virtually all planting in the Sandhills has been limited to 1-0 nursery-grown seedlings. However, erratic results obtained in past planting of conventional 1-year-old stock on typically poor sites led us to the investigation of older stock. A study was established in cooperation with the South Carolina State Commission of Forestry to grow and outplant 2-year-old stock, including transplants. Some special stock-conditioning measures were included in the test. For example, the conventional 1-0 stock in the nursery had to be lifted and then hand-planted to obtain the larger 1-1 transplant seedlings (fig. 13). Because of the extremely long roots produced by these transplants, root pruning to 6 inches at the time of outplanting was necessary. Half of each stock class was foliage-clipped to 5 inches in length.

Figure 13.--1-1 longleaf pine transplants at time of lifting from the nursery beds. Horace Tilghman Nursery, S. C.

Table 12.--First-year survival of longleaf pine seedlings of different ages when outplanted on cleared Sandhill scrub oak sites

Age of stock	Clipped 5 inches	Unclipped
	- - Percent survival - -	
1-0	84	87
1-1 transplant	66	34
2-0	58	65

The conventional 1-0 stock showed the best first-year survival. Except for the unclipped 1-1 transplants, survival among the older seedlings was quite uniform and fairly satisfactory (table 12).

On the basis of the foregoing nursery treatments, certain general specifications for quality seedling stock can be given as an early guide to planting longleaf under Sandhill conditions. The principal factor is seedling size, or morphological grade. Although size

alone does not always assure high survival, lower bed densities and fertilization treatments tend to produce larger stock. Until research can more completely define physiological qualities of seedling grades, a good interim guide for planting on harsh sites is general appearance or size of longleaf stock.

The most successful longleaf survival in our tests was obtained with 1-0, foliage-clipped, grade 1 seedlings, planted in winter, with roots pruned to no less than 5 inches in length at lifting time. Seedlings should be grown at low to medium bed densities. Proper fertilization and careful root-pruning in midsummer are desirable. When available, fall-sown nursery stock originating from a local or more northerly Sandhills seed source is recommended for planting on Sandhill sites.

By planting seedlings with the above characteristics on prepared sites, the survival of longleaf may be boosted to a point where it will compare favorably with that of slash and loblolly pines on dry sites.

PLANTING ON SCRUB OAK SITES

Plant competition for soil moisture, nutrients, and growing space is very intense on Sandhill sites. In scrub oak or in old fields, this competition should be partially or completely removed to insure satisfactory early survival and growth of planted seedlings.

The intensity of competition from roots is strikingly demonstrated by the effect of scrub oak stands on seedling heights along the borders of old-field plantations. This "sapping effect" was observed on the first three rows of a 6-year-old slash pine plantation, the competitive effect extending 30 feet or more from the scrub oak area (fig. 14).

Figure 14.--Scrub oak adjoining a 6-year-old slash pine plantation established in an old-field. The border competition from the scrub oak has stunted the first three rows of pine. Sand Hills State Forest, S. C.

Complete Eradication

Complete mechanical clearing of scrub oak on a large scale was begun in 1947 in the Sandhills by the South Carolina Commission of Forestry. Various kinds of equipment, including the Marden brush cutter (fig. 15) or a heavy steel cable drawn between two tractors, are employed to remove the scrub oak. These operations are followed by plowing and disking with a fire-break or gang-disk plow, to further reduce sprouting. Over 800 acres of scrub oak land were cleared on the Sand Hills State Forest in South Carolina between 1950 and 1954. A recent report shows that brush cutting and plowing on these lands has averaged $9.61 per acre, but this figure includes rather low labor and equipment costs. Commercial costs of these methods may average considerably more (7). A portion of this cost can be defrayed by renting cleared areas to watermelon growers 1 year in advance of tree planting.

Recently, the South Carolina State Commission of Forestry has tested a new method of land conversion. This consists of a crawler tractor pulling a triangular-shaped blade which uproots and severs all scrub oak stems below ground and the sprouting portion of the tree. This "undercutter" leaves the residue of stems, twigs, and debris in place. The land is left semirough in a series of broad, V-shaped furrows approximately 8 feet apart (fig. 16). Although the residue may aid in conserving moisture during the first critical year, partly buried debris may make machine planting difficult. Undercutting by this method should be done several months in advance of planting, to allow the scrub oak to decay. Very little first year resprouting has been reported. Site preparation by this method appears promising but may require further testing. In South Carolina over 2,800 acres have been completed on a commercial basis. Contract clearing costs, exclusive of planting, have been reported as low as $11.00 per acre.

Fire as a tool for mass scrub oak eradication has been largely unsuccessful in the Sandhills. The principal reason is the lack of adequate fuel on the ground to carry an effective fire. Also, this method of eradication reaches only the above-ground portions of the stem and has proven to be ineffective in reducing sprouting. In fact, areas have been observed where fire actually increased the number of sprouts from existing root stocks. Recently, fire has been used to dispose of brush windrowed by bulldozing operations. In such instances, fire is a supplemental tool for complete eradication.

Mass eradication by use of chemicals has not been tried extensively. Recent reports from other regions indicate that aerial spraying from helicopters is feasible under certain conditions. At present, chemicals can be used most effectively to release established seedlings on a stem-wise basis.

Soil Stabilization Improves Longleaf Survival

Much of the early planting of longleaf pine on cleared scrub oak areas was generally unsuccessful. On the Sand Hills State Forest, survival seldom exceeded 20 to 30 percent, even when conventional methods of land clearing were used. One factor which may have caused a big difference in the early survival of longleaf plantations was the unstable soil conditions resulting

Figure 15.--Site preparation by complete clearing of scrub oak. Above, as a first step trees are uprooted and chopped with a Marden brush cutter. Below, further preparation is often done with a heavy disk harrow, which leaves the site in the illustrated condition.

Figure 16. --Another land-clearing operation on scrub oak land. Bulldozer blade knocks down larger trees, and a triangular-shaped blade at rear uproots residual scrub oaks and severs roots below ground. Manchester State Forest.

from the clearing and disking operations. Air pockets and soil washing seriously reduced survival unless treated areas were allowed to stabilize for about a year before being planted. In brief, we needed to know what supplemental treatments were required to insure soil stability within a short period of time. Our tests showed that dragging the cleared sites as an additional site preparation measure to speed soil stabilization boosted initial survival by 20 percent over similar undragged areas (table 13 and fig. 17). Comparable survival benefits were obtained by plowing single furrows with a Mathis-type plow in the previously cleared and disked areas, although in this case the primary function of the single furrows may have been improved soil moisture rather than soil stabilization.

After the soils have been cleared and plowed; they should be dragged and allowed to stabilize for a minimum period of 6 months, preferably during fall and winter (table 13). The stabilization period results in better soil compaction and makes it easier to place the seedling in the planting hole. When areas are not dragged or not allowed to settle properly, air pockets and soil washing are detrimental to newly planted longleaf seedlings.

Table 13.--The effect of soil stabilization and site preparation on first-year longleaf survival

Scrub oak treatment	Soil stabilization period	Average first-year survival
	Months	Percent
Complete eradication followed by:		
Disking and dragging	6	82
Single, deep (10-inch) furrows	6	80
Disking (not dragged)	6	63

Figure 17.--After clearing and disking, soil stabilization on the former scrub oak site can be hastened by a dragging operation (above), or by furrowing (below).

Partial Eradication--Furrowing

The high cost of complete scrub oak eradication led to an investigation of furrowing, or partial eradication as a possible low-cost substitute (11, 12). Information obtained from these studies pointed to the fact that deep furrows apparently set up a micro-environment well suited to the establishment of longleaf pine. Furrows offer some protection to the seedlings from drying winds, extremes in temperature, and soil evaporation during the initial critical growing season. This moderating influence probably reduces the transpiration rate of the planted seedlings.

Furrows should be 6 to 8 feet apart, 8 to 10 inches deep, and about 18 inches wide. Such furrows can be plowed by a Sieco double-disk plow drawn by an ordinary crawler tractor. This technique will remove over 80 percent of the scrub oak stems, leaving the remaining stems standing between furrows (fig. 18).

Figure 18.--Partial scrub oak eradication by deep (10-inch) furrows followed by hand planting. Manchester State Forest, S. C.

Longleaf survival following various methods of scrub oak control, including a 90-day stabilization period before planting was:

Treatment	First-year survival (Percent)
Furrowed (8-10 inch depth)	81
Complete eradication (plowed, disked, and dragged)	63
Furrowed (5-inch depth)	61
No eradication (control)	52

As shown in the tabulation, deep furrows in scrub oak followed by hand planting significantly improved longleaf survival. Survival was poorer in the completely eradicated area because 90 days is too short a stabilization period. However, surviving seedlings had high vigor because of more available soil moisture (fig. 19).

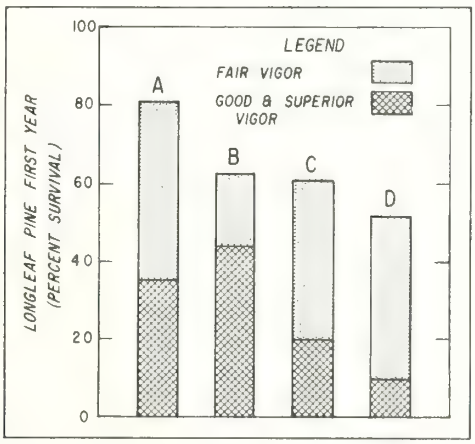

Figure 19.--Good and superior vigor seedlings expressed as a percent of total survival. A, furrowed 10 inches deep, removing 80 percent of stems. B, complete removal (plowed, disked, and dragged). C, furrowed 5 inches deep, removing 80 percent of stems. D, control, no removal.

Although our early tests with longleaf pine involved a 2-step planting method (site preparation followed by hand planting), private industry has successfully employed a 1-step method for slash and loblolly pines in scrub oak areas. The West Virginia Pulp and Paper Company has recently applied this technique to small acreages of Sandhill lands by using a heavy HD-9 crawler tractor and a Mathis plow in tandem with a planting machine (fig. 20). Other public agencies, such as the North Carolina Division of Forestry, employ a 2-step process: furrowing followed by either machine or hand planting. Much of this work consists of constructing shallow furrows 2-3 inches deep with a Mathis plow pulled through scrub oak areas by a TD-9 tractor (fig. 21).

Seedling Release After Planting

Even though first-year survival is good, survival and growth in the future may be prevented or limited by sprout competition, especially with the slower-starting longleaf pine. To obtain the maximum growth from established seedlings, some type of release or weeding during the early life of the plantation may be necessary. Under such conditions, questions arise as to when release is most effective, how much is needed, and what are the most efficient and economical techniques.

Photo by West Virginia Pulp and Paper Co.

Figure 20. --One-step method of partial scrub oak eradication and planting. Slash pine planted in deep furrows by HD-9 tractor and a modified Mathis plow in tandem with a tree planting machine.

Figure 21.--Scrub oak area furrowed with a Mathis fire plow and crawler tractor. Slash pine planted in the furrows are 2 years old. Release from resprouted scrub oak competition will be needed before pines reach maturity. Bladen Lakes State Forest, N. C.

The need for pine release from sprouting scrub oak exists in two general conditions on Sandhill sites. The first of these occurs where scrub oak has resprouted following mechanical clearing. A second condition exists after furrow planting, where a portion of the scrub oak remains between furrows.

To develop positive control measures for the described situations, a test of chemical control techniques was started in cooperation with the South Carolina State Commission of Forestry. Four methods were applied to a new group of 40 turkey oaks each month for 12 successive months. Stems ranged from $\frac{1}{2}$ to 4 inches in diameter. The methods were: Cornell tool with Ammate (8 pounds to 1 gallon of water); notches with Ammate crystals (1 to $1\frac{1}{2}$ oz. per notch); stump spray; and basal spray. The spray mixture used in the latter two treatments consisted of 1 gallon of 2, 4, 5-T (4 pounds acid equivalent per gallon) to 20 gallons of oil.

Basal and stump spray results were generally good, with the winter treatments least effective (table 14). A poor kill was obtained in the fall with Ammate applied in notches, but results were extremely good at all other times. A poor kill was obtained with the Ammate-Cornell tool treatment regardless of season of application.

It was not possible to obtain cost data in this study. However, earlier investigations on the Santee Experimental Forest showed that basal spraying with 2, 4, 5-T was almost as cheap as cutting the competing stems with a machete without chemical treatment. In contrast, where the competing stems were cut and the residual stumps sprayed with 2, 4, 5-T, the cost almost doubled (9, 10). Thus, under Sandhill conditions, where extensive acreages of small-diameter stems are prevalent after clearing or furrowing, the basal spray with 2, 4, 5-T appears to be the cheapest, most effective treatment.

Where partial scrub oak eradication or furrowing is employed for improving early survival, the deterring effect of the residual scrub oak on subsequent seedling growth may be substantial. Under a less intensive scrub oak treatment, such as single deep furrows, resprouting and reinvasion of scrub oak roots into the furrows is quite likely. Consequently, the question of the need for releasing longleaf pine from the remaining scrub oak stems left between furrows may be important. When, if at all, should residual scrub oak be controlled?

Table 14.--Dead small-diameter scrub oak stems 2 years after treatment [1]
(In percent)

Season [2] treated	Ammate, Cornell tool	Ammate, notches	Stump spray, 2, 4, 5-T	Basal spray, 2, 4, 5-T
Spring (March, April, May)	10	87	83	80
Summer (June, July, August)	13	83	70	90
Fall (Sept., Oct., Nov.)	3	37	87	83
Winter (Dec., Jan., Feb.)	3	80	53	47

1/ Dead is defined as those trees with both stem and roots dead two growing seasons after treatment.

2/ Each season is the mean of 3 months' treatment.

A scrub oak area on the Savannah River Project was used to test the effect of release after two growing seasons. In 1954, (1-0) longleaf seedlings were hand-planted in deep (10-inch) furrows. The furrows were made with a Sieco fire plow. As a result of the site preparation, approximately 85 percent of the small-diameter stems ($\frac{1}{2}$ to 6 inches d.b.h.) were removed. Twenty rows of 25 seedlings each were planted to longleaf pine at a 6x6-foot spacing. First-year survival was excellent, averaging over 86 percent.

In 1956, two growing seasons after planting, one-half of the seedlings were released by poisoning all residual scrub oak with Ammate; the remaining half were left untreated (fig. 22). A vigor tally was made of all seedlings immediately before the release treatment and again 1 year later.

A significant improvement in vigor occurred on released plots. The results showed that compared to untreated areas the release treatment more than doubled the percent of trees beginning active growth. In all instances the effect of release was to move each vigor class toward earlier height growth. No direct comparisons are available at this time of the effect of an earlier release, either at the time of planting or after a single growing season. However, the test indicated that release delayed as long as the end of the second growing season after planting is still highly beneficial.

Early growth of slash pine is generally more rapid than that of longleaf, often averaging 2 to 3 feet in height annually. Under such conditions, a single release treatment, properly timed, appears to be adequate. A second release is generally unnecessary, because 4-year-old slash pine can successfully compete with the remaining scrub oak sprouts (fig. 23). Once crown closure has occurred in young plantations, scrub oak is no longer a problem.

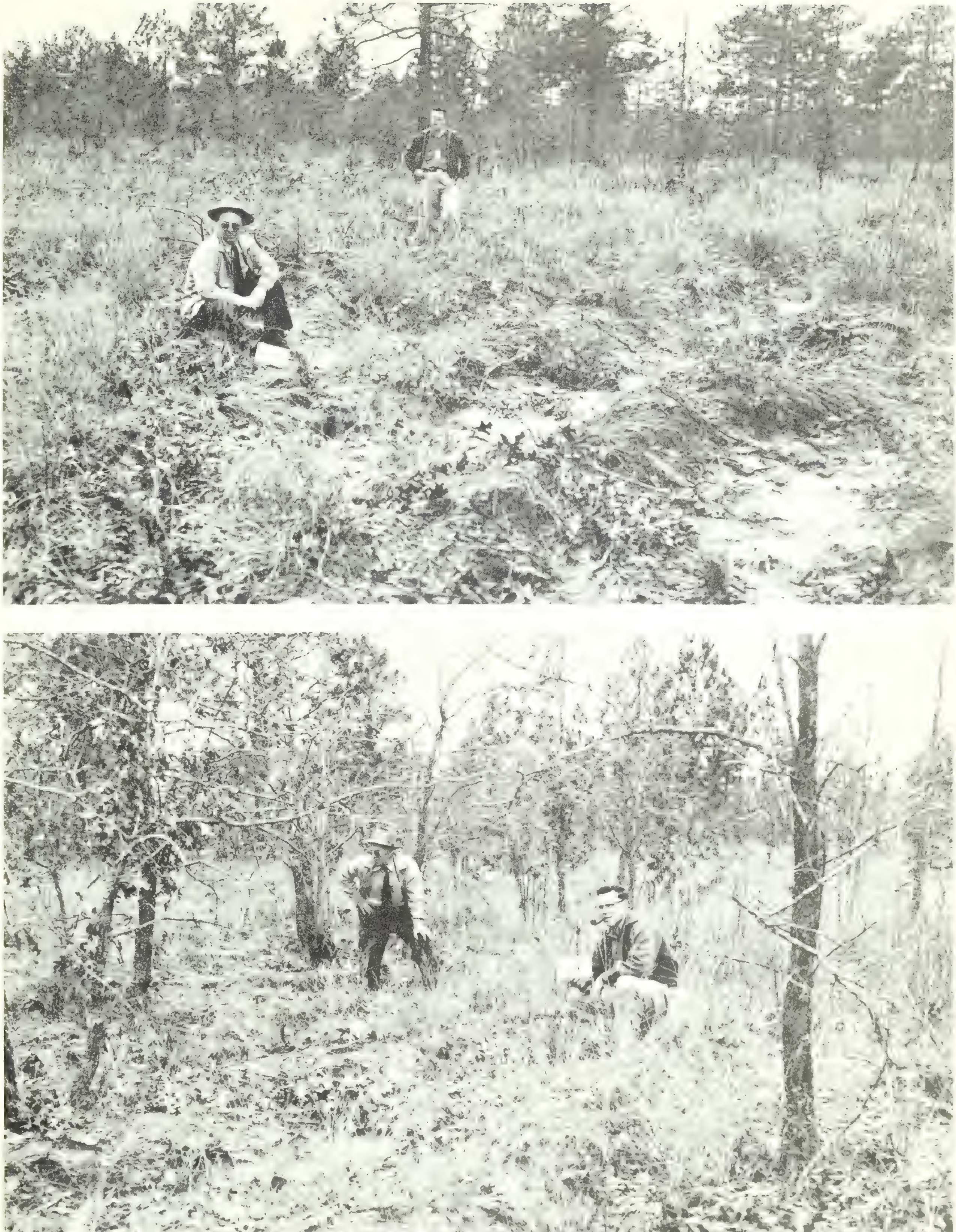

Figure 22.--Above, scrub oak poisoned to release longleaf seedlings. The poisoning was done 2 years after the seedlings were planted. Picture taken 1 year after release; 35 percent of seedlings beginning active height growth. Below, no release. Only 15 percent of seedlings emerging from grass stage.

Figure 23.--Four-year-old slash pine seedlings free to grow after a single release from scrub oak competition.

PLANTING ON OLD-FIELD SITES

The single largest planting program in the Sandhills at the present time is the Savannah River Project of the Atomic Energy Commission. Since 1952, this agency has annually planted an average of 9,000,000 seedlings on old abandoned fields. The total planted to date is approximately 45,000,000 seedlings, and the program is designed to continue planting at this rate for the next 3 years. In addition to the old-field plantings, nearly 30,000 acres of scrub oak land are in need of artificial regeneration.

Removing Competition by Furrowing

Grasses and weeds on old-field Sandhill sites offer considerable competition to planted seedlings, and in most instances appear to be as detrimental as scrub oak roots to early survival. Grass and weed competition on old fields varies according to the period of abandonment or successional stage. In the South Carolina Sandhills many fields are predominantly in wiregrass and broomsedge. Such vegetation competes severely with newly planted seedlings, the mat of surface roots robbing pines of soil moisture during the critical growing season (fig. 24).

Figure 24.--Typical old-field planting site on the Savannah River Project, showing ground cover of 7 to 8 year "rough" of weeds and grasses.

One test was in an old field with a 7 year "rough" of annual weeds and grasses. Four $\frac{1}{4}$-acre plots were prepared with a tractor-drawn Sieco plow which made a single furrow about 8 inches deep and 24 inches wide. Four plots were left unfurrowed as checks. In each treatment 1,200 (1-0) longleaf seedlings were planted at a spacing of 4x6 feet. First-year survival on the furrowed plots was 92 percent, in contrast to adjacent untreated areas, where survival was only 59 percent. Vigor on furrowed plots was outstanding, indicative of the better soil moisture conditions in the vicinity of the planted seedlings (13). This test gave good evidence that root competition in old fields should be removed before or at the time of planting longleaf in the Sandhills.

Why Furrow Planting Improves Survival

The effects of furrowing on survival and moisture content of the soil were investigated in a recent cooperative study with the Savannah River Project. Soil moisture determinations were made at approximately 10-day intervals on furrowed and unfurrowed planted areas. Soil samples were taken at 3- and 9-inch depths during the 1956 growing season. On furrowed areas, samples were obtained from the base of the furrow. Soil moisture determinations were made by oven-drying, and a laboratory analysis established the wilting point for the soil.

Results showed that available moisture on furrowed areas remained above that of untreated plots throughout the course of the growing season. In the untreated area, soil moisture was definitely below the wilting point for an extended period (fig. 25). At the 9-inch depth the most critical period was in June, when only 1.1 inches of rainfall was recorded. During the same interval, soil moisture was at or just above the wilting point in the furrows, indicating that some moisture was available at the 9-inch depth during the driest part of the growing season. This all indicates that better moisture conditions exist in furrows and at depths available to roots of planted seedlings.

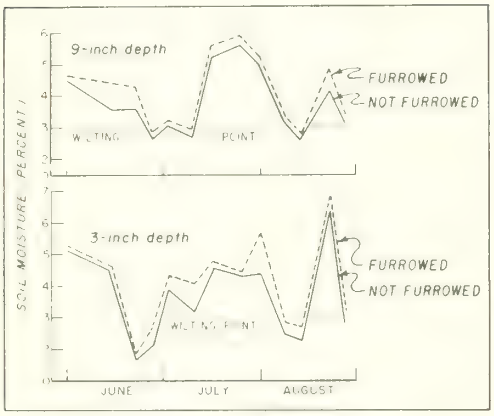

Figure 25.--The soil moisture record on old-field sites during the critical growing season months of 1955 at the Savannah River Project.

"Prescription Planting"

Our early investigations indicated that the relation of seedling grade to expected survival could have great economic significance in planting. Thus, on dry sites, the choice of spacing in pine plantations would depend upon survival and on the number of trees per acre desired at the time of the first thinning. The number of trees planted should be sufficient to allow for expected mortality.

The effect of seedling grade on survival in our study plots influenced the Project Forester of the Savannah River Project to make survival counts by species, morphological grade, and soil type, beginning with 1953-54 plantations (table 15 and fig. 26). Analyses of these and later first-year survival

Table 15.--First-year longleaf and slash pine survival, as affected by seedling grade and soil type on old fields of the AEC, Savannah River Project

Morphological grade 1/	Soil type	Species and planting season			
		Longleaf pine		Slash pine	
		1953-54 2/	1954-55 3/	1953-54	1954-55
		- - - Percent survival - - -			
1	Sandy loam	24	60	60	100
1	Sand	23	59	50	89
2	Sandy loam	18	51	49	89
2	Sand	23	41	48	75
3	Sandy loam	10	33	43	67
3	Sand	8	11	23	50

1/ Morphological grade specifications according to Wakeley (18).
2/ Driest year of record.
3/ Good rainfall distribution.

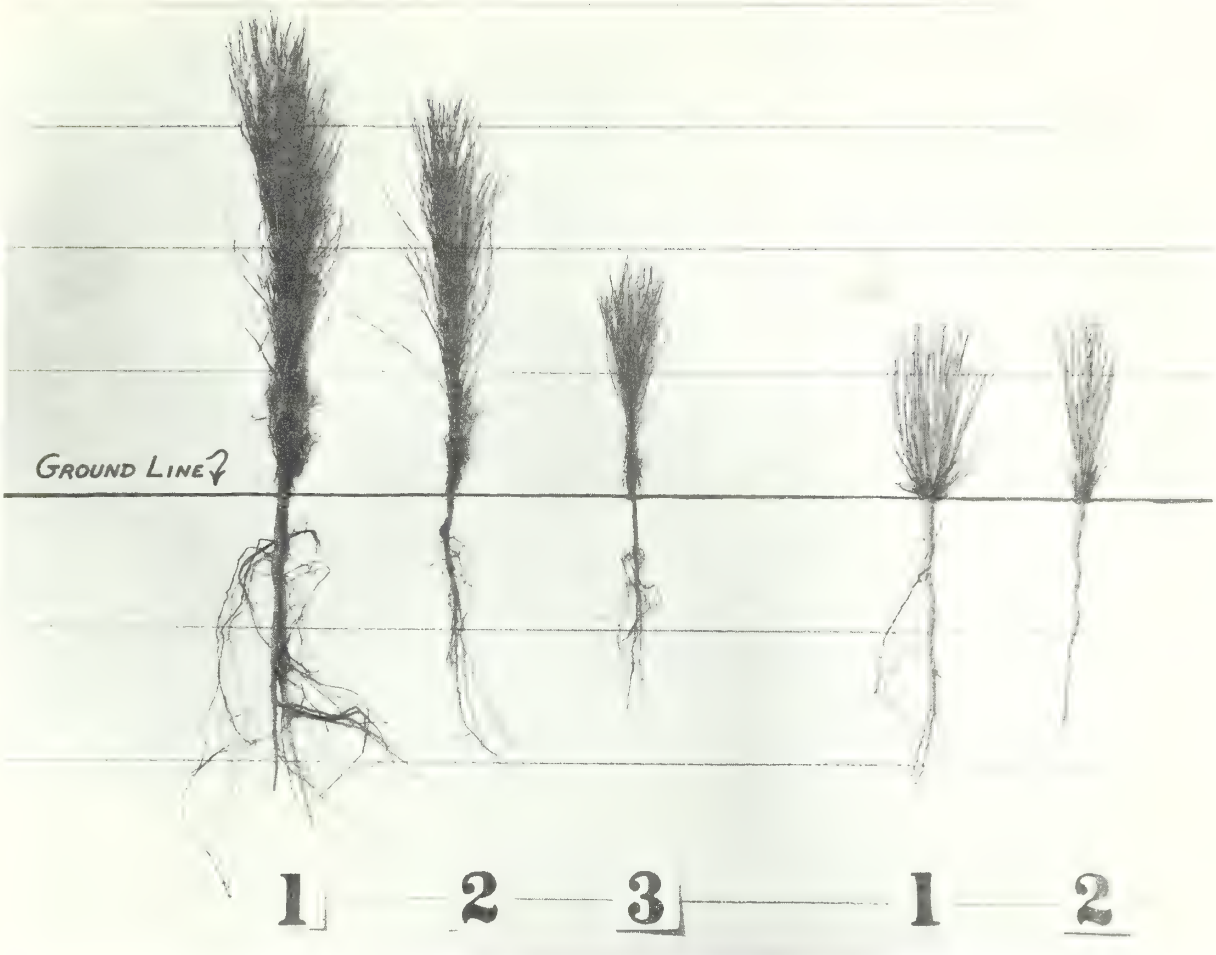

Figure 26.--Comparison of seedling morphological grades. Left, slash pine, grades 1, 2, and 3. Right, longleaf pine, grades 1 and 2.

counts led to the development of a "prescription" for planting on old-field sites by Project Forester Hatcher (4, 5), whereby number of seedlings planted per acre is predetermined for each field according to expected survival by grades and prevailing soil type. Thus, enough trees of selected grades are planted per acre to insure a successful, manageable plantation. The current prescription for conditions on old fields of the Savannah River Project in South Carolina is given in table 16. The same principles can probably be applied elsewhere by examining survival by species, soils, and site conditions for local young (1- to 3-year-old) plantations, and determining from discussion with nurserymen and from nursery records the approximate grade percentage planted.

Hatcher (5) found that the gain is considerable. For plantations in this area of the Sandhills, the method reduced per-acre planting costs in one year 23.5 percent in spite of supervision and service costs running $1.21 per thousand seedlings over the previous 3-year average. By prescription planting, the seedlings have been spread over a larger area, with a reduction in the cost per acre and without lessening the chances of a well-stocked stand. This is the first large-scale use of prescription planting in the South.

The benefits of furrowing observed in the experimental trials described have led to its use in planting the old fields of the Savannah River Project. Furrows about 14 inches wide and 4 inches deep are made with a 26-inch disk located immediately in front of the planting machine coulter on both single and double planters (fig. 27). In the Sandhills, slash and longleaf pines should be planted at the bottom of the furrow. On slightly rolling areas the planting is done on the contour of the land to prevent washing. Observations made in 1956 indicate that furrow planting is highly successful, in contrast to conventional planting methods.

Table 16.--Prescription planting on old-field sites

Longleaf Pine — Sandhills Sites

	Grade 1 Expected Survival Unfurrowed*	*Grade 1* Expected Survival Furrowed***	*Grade 2* Expected Survival Unfurrowed*	*Grade 2* Expected Survival Furrowed***
All sandy soils; deep sands, loamy sands, sandy loams..........	40-45%	70-75%	30%	50%
Spacing (feet)...................	6 x 5	6 x 8	6 x 4	6 x 6

*Grade 1, ¼" plus at root collar; Grade 2, $\frac{3}{16}$-¼" at root collar. Root length at least 5" and well developed lateral roots.
**Seat bottom of bud on top of loose soil raised by planting shoe to avoid silting over bud.

Spacing and number per acre:

6 x 4........1815	6 x 7........1037
6 x 5........1452	6 x 8........ 907
6 x 6........1210	6 x 9........ 807

Slash Pine — Sandhills Sites

	Grade 1 Expected Survival Unfurrowed*	*Grade 1 Expected Survival Furrowed*	*Grade 2* Expected Survival Unfurrowed*	*Grade 2 Expected Survival Furrowed*	*Grade 3* Expected Survival Unfurrowed*	*Grade 3 Expected Survival Furrowed*	*Grade 3 Expected Survival Furrowed & Planted Deep***
Deep Sands..................	60%	80%	50%	70%	30%	50%	65%
Normal Spacing (Feet).........	6 x 7	6 x 9	6 x 6	6 x 8	6 x 4	6 x 6	6 x 8
Loamy Sands.................	65%	85%	55%	75%	30%	60%	75%
Normal Spacing (Feet).........	6 x 8	6 x 9½	6 x 6	6 x 9	6 x 4	6 x 7	6 x 8½
Sandy Loam	70%	90%	60%	80%	45%	65%	80%
Normal Spacing (Feet).........	6 x 8	6 x 10	6 x 7	6 x 9	6 x 5	6 x 8	6 x 9

*Grade 1 specification: Top 6-14", stem diameter $\frac{3}{16}$" at ground level (root collar).
*Grade 2 specification: Top 6-12", stem diameter ⅛-$\frac{3}{16}$" ground level (root collar), all secondary needles.
*Grade 3 specification: Top 3-8", stem diameter $\frac{1}{16}$-⅛" ground level (root collar), at least 5 bundles of secondary (long) needles.

Root length at least 5" for all grades, and well developed lateral root system.

Keep roots moist at all times with soupy mud or wet moss and covered with wet burlap. Do not let stand in water.

**If grade 3 (small) seedlings are planted deep in furrows—so just the bud is above ground line—survival is increased by at least 15-30%. Planting bar or machine must go deep enough to avoid U-rooting.

Spacing and number per acre:

6 x 4........1815	6 x 7........1037
6 x 5........1452	6 x 8........ 907
6 x 6........1210	6 x 9........ 807

Figure 27.--Furrow planting on old-field sites of the Savannah River Project. Above, double planter employing a 26-inch disk in front of the coulter. Below, completed furrow planting which follows the contour on slightly rolling areas.

SUMMARY

This paper represents 4 years of intensive experimental investigations aimed at finding useable guidelines for Sandhills planters. Some of the information is derived from past experience, but most is the result of critical observations. The research applies principally to longleaf pine, inasmuch as artificial regeneration of this species is one of the most pressing problems. A multitude of experimental plantations have been established throughout the Sandhill Region, mostly in South Carolina. Foresters will be able to follow the development of these plantations for many years to come.

The keys to successful longleaf pine plantation establishment on Sandhill lands are: (1) prepare the site properly by clearing or furrowing, allowing a proper soil stabilization period; and (2) plant the highest quality nursery stock available.

Longleaf Pine Planting Guide

Seed source	Obtain longleaf seedlings grown from seed of a local or upper Coastal Plain source.
Planting stock	Use 1-0 longleaf pine seedlings grown at low to medium seedbed densities, not more than 20-25 per square foot.
	Plant only grades 1 or 2: cull all morphological grade 3 stock[4/] and stock showing brown-spot infection.
	Clip foliage to about 1/3 needle length if naturally longer than 6 to 8 inches.
	Prune long roots to no less than 6 inches at lifting time. Midsummer pruning (July) is advantageous if properly done in the nursery beds.
	Utilize stock which has been given proper applications of NPK fertilizers according to nursery soil requirements.
Site preparation in scrub oak	Completely clear, plow (disk), and drag, using heavy, tractor-drawn equipment. Allow a minimum of 6 months soil stabilization before planting...

4/ Needles less than 8 inches long, often scanty; stem less than 3/16 inch thick, and no winter buds present.

	or, plow single (8-10 inch) furrows, 6 to 8 feet apart with fireplow or similar heavy equipment. Allow a minimum of 30 days for stabilization; if less, plant seedlings about $\frac{1}{4}$ to $\frac{1}{2}$ inch higher than usual to avoid excessive silting.
Site preparation in old fields	Plow single furrows 6 to 8 feet apart to a depth of 3-4 inches, either before or at time of planting. If done before planting, allow 30 days for stabilization; if 30 days cannot be allowed, plant seedlings about $\frac{1}{4}$ to $\frac{1}{2}$ inch higher than usual.
Planting	Machine plant whenever possible, especially in old-field and cleared scrub oak sites. For large areas in scrub oak, furrow planting requires heavy equipment; smaller areas can be hand-planted satisfactorily in single furrows. Winter planting (December and January) is preferred.
Seedling release	On cleared and furrow-planted areas, poison sprout growth or residual scrub oaks in close competition with planted pine. This is best if applied during the growing season, not later than the second growing season after planting.
Chemical release methods	Effective chemical control of small-diameter scrub oak includes: (a) A mixture of one part 2,4,5-T (4 lbs. acid equivalent) to 20 parts of fuel oil, applied as a basal spray or to fresh stumps. (b) Ammate crystals applied in notches.

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The Relation of Growth to Stand Density in Natural Loblolly Pine Stands

by

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The Relation of Growth to Stand Density in Natural Loblolly Pine Stands

5-Year Results

by

K. F. Wenger, T. C. Evans, T. Lotti, R. W. Cooper, and E. V. Brender [1/]

INTRODUCTION

This is a progress report of a regional study on growing-space requirements for natural stands of loblolly pine (Pinus taeda L.).

A primary objective is to measure the effects of residual stand density, obtained naturally or by cutting, during intermediate ages, upon volume yield and total production. By imposing real values and costs upon measured yields, net return may be calculated and used to determine optimum levels of stand density for various combinations of site, product, and financial goal.

The attainment of this objective obviously depends on a series of measurements taken over a long period. Only preliminary and partial results are reported herein because data are complete only for the first 5-year period of the study. Nevertheless, these data indicate that a low level of stand density is optimum for growth on a poor site, at least in young loblolly pine stands. In contrast, a good site will support a relatively high stand density throughout the rotation. Because of the preliminary nature of these findings, no attempt is made to develop financial aspects of the study at this time.

METHODS

A total of 153 circular $\frac{1}{4}$-acre plots with $\frac{1}{2}$-chain isolation strips were selected in 20- to 60-year-old stands of a wide range of site indices and densities. Site indices ranged from a little less than 60 feet to a little more than 100; densities ranged from 40 to 130 percent of full stocking (7). Only essentially pure stands of even-aged, uniformly spaced, and insect- and disease-free loblolly pine were used. Site index could not vary more than 10 feet within plot boundaries.

1/ L. E. Chaiken, now Professor of Forestry at Duke University, and T. A. McClay, now of the Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service, also were responsible for important portions of the study. The West Virginia Pulp and Paper Company made land available in the Westvaco Experimental Forest, Georgetown, S. C., and L. T. Easley and D. A. Harkin of the Company staff assisted in the work. The Georgia Kraft Company, Macon, Ga., supplied substantial assistance for the remeasurement of the Georgia portion of the study.

Plots were established in Georgia, Virginia, and South Carolina on the Hitchiti, Camp,[2] Santee, and Westvaco Experimental Forests during the period 1948-1950.

Stand measurements on the plot consisted of a tally of all pine stems 0.6 inch d.b.h. and larger by 1-inch diameter classes. Only those hardwoods 4.6 inches d.b.h. and larger were tallied. Site index was determined by measuring total height and age of a sample of dominant and codominant trees, and applying the readings to Coile's (3) site index curves. These initial measurements were used to determine merchantable cubic-foot volume, board-foot volume (International $\frac{1}{4}$-inch log rule), and stocking per acre. Board-foot and cubic-foot volume tables based on total height were constructed from data that had been collected earlier in the Hitchiti, Santee, and Camp Experimental Forests.

About 35 percent of the number of plots were cut to specified residual densities, to provide a comparison between the growth of thinned and unthinned stands of the same age, density, and site. The thinnings were essentially from below, but modified to permit uniform spacing of residual stems and the removal of undesirable trees in all crown classes. Hardwoods 4.6 inches d.b.h. and larger were poisoned.

All of the plots were remeasured after five growing seasons. Growth was expressed in terms of the net annual increment in cubic-foot and board-foot volume per acre. Regression methods were used to determine the relation of growth to the age, site index, and density of the stand.

The form of the function fitted to the data was as follows:

$$Y = b_0 + b_1\left(\frac{1}{A}\right) + b_2(S) + b_3(D) + b_4(D^2) + b_5\left(\frac{S}{A}\right) + b_6\left(\frac{D}{A}\right) + b_7\left(\frac{D^2}{A}\right) + b_8(SD) + b_9(SD^2)$$

in which Y = growth

A = total age

S = site index

D = density percent

b with subscripts = coefficients derived from the data.

Density percent expresses the basal area of a stand of given average diameter as a percentage of the basal area of well-stocked stands of the same average diameter. Reineke's (6) stand density index (SDI), Chisman and Schumacher's (2) tree-area ratio, or other measures of stocking might have served equally well.

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[2] Maintained in Surry County, Virginia, by the U. S. Forest Service in cooperation with the Union Bag-Camp Paper Corporation.

RESULTS

Cubic-Foot Volume Growth

The relations of growth in cubic feet per acre to site index, stand age, and stand density percent (7) derived from the data were as follows:

$$\text{PAG (thinned)} = 272.08 - 2.47(S) - 5.72(D) + 0.074(SD)$$

$$\text{PAG (unthinned)} = -91.36 + \frac{4908.0}{A} - 0.075(S) - 51.79\left(\frac{D}{A}\right) + 0.0289(SD)$$

in which PAG = periodic 5-year annual growth in cubic feet per acre of trees 4.6 inches d.b.h. and larger,

A = age of stand in years at the beginning of the 5-year period,

S = site index of stand,

D = percent of theoretical full stocking after thinning or at the beginning of the 5-year period.

In the thinned stands, the relation of growth to density varied with site index (fig. 1). No significant effect of age was found. Heavier stands grew faster than lighter stands on good sites but slower on poor sites. Since the trend on poor sites is negative within the range of densities sampled, it must be positive at lower densities. Thus, the true relation must be curvilinear, and growth rate must reach a peak somewhere near or below the lower limit of the sample. The difference in trends with site also indicates, therefore, that maximum growth occurs at a higher density on good sites than on poor sites.

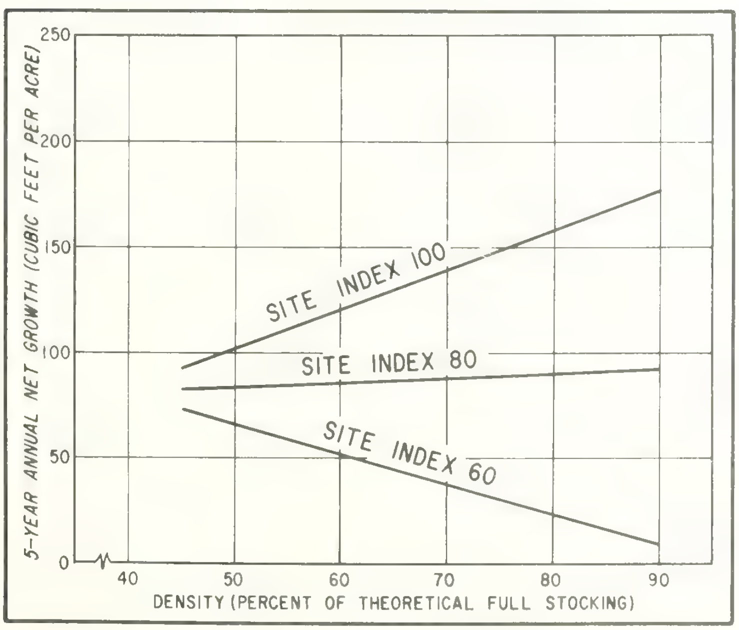

Figure 1.--Cubic-foot volume growth of thinned stands in relation to stand density and site index.

In the unthinned stands, the relation of cubic-foot volume growth to stand density varied with age as well as with site index. At young ages, growth was related to density in essentially the same way as in thinned stands, increasing with increasing density on good sites and decreasing on poor sites, within the density range sampled (fig. 2A). In older stands, however, growth increased with increasing density on all sites, although the difference was greater on good than on poor sites (fig. 2B).

The effect of cutting on stand structure may be the reason why age was a significant factor in the growth of the unthinned stands but not of the thinned stands. In an unthinned stand on a given site, the size of trees is related to the number per acre and the stand age. Thinning destroys this relation, and in thinned stands the number per acre is determined mainly by the heaviness of the thinning. Thus, any effect of age is likely to be obscured in the early years after thinning. As the prescribed densities are maintained for extended periods, growth may again be more strongly related to age.

Board-Foot Volume Growth

In thinned stands, the relations of board-foot volume growth per acre to age, site, and density were as follows:

$$PAG = -484.09 + \frac{14657.86}{A} + 3.68(S) - 407.75\left(\frac{D}{A}\right) + 0.204(SD)$$

In unthinned stands, they were:

$$PAG = -1054.61 + \frac{47971.81}{A} + 4.04(S) - 154.68\left(\frac{S}{A}\right)$$

$$-602.99\left(\frac{D}{A}\right) + 0.259(SD)$$

in which PAG = periodic 5-year annual volume growth per acre of trees 9.6 inches d.b.h. and larger to a 7-inch top diameter inside bark, in terms of the International $\frac{1}{4}$-inch log rule.

In both thinned and unthinned stands, the relation of board-foot volume growth to density varied with age as well as with site index. In young stands, growth increased with increasing density on good sites, but decreased on poor sites within the density range sampled (fig. 3). But in older stands, growth increased with increasing density on all sites, although the increase in growth was not as great on poor as on good sites (fig. 4). This difference with age in the relation of board-foot volume growth to density indicates, therefore, that the density for maximum growth is higher in older than in younger stands.

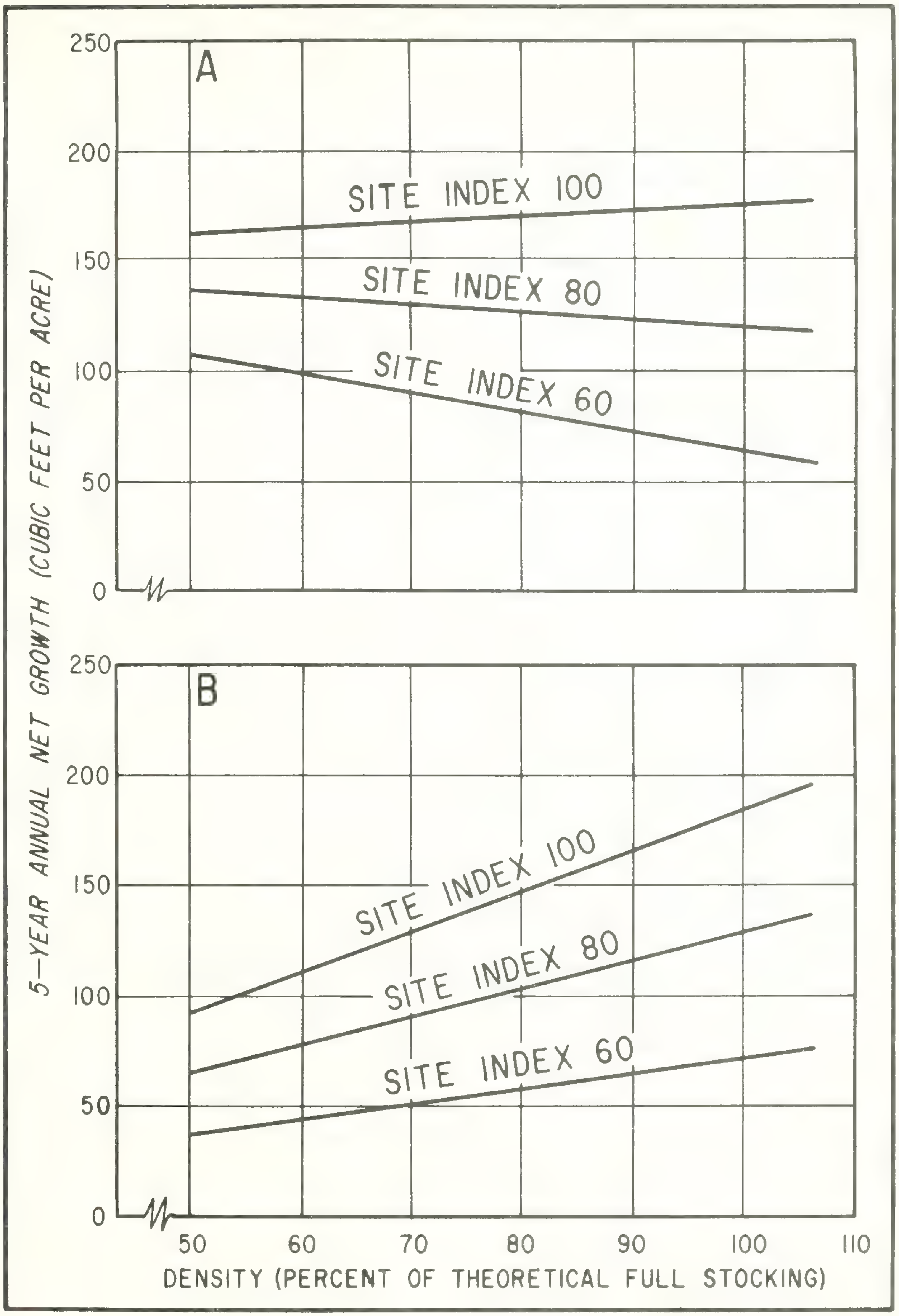

Figure 2.--Cubic-foot volume growth of unthinned stands in relation to stand density and site index. A, at 20 years; B, at 50 years.

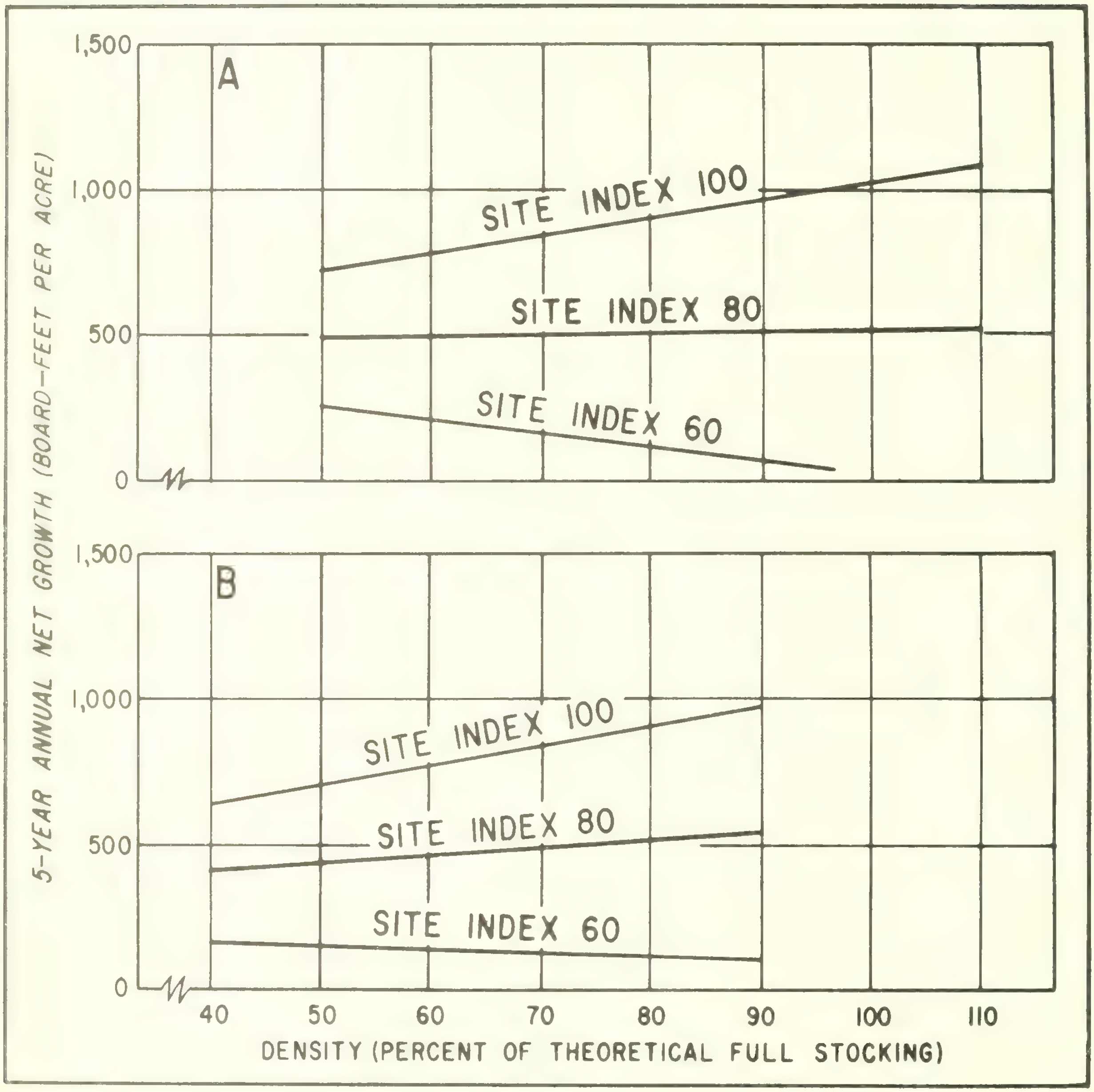

Figure 3.--Board-foot volume growth of 30-year-old stands in relation to stand density and site index. A, unthinned; B, thinned.

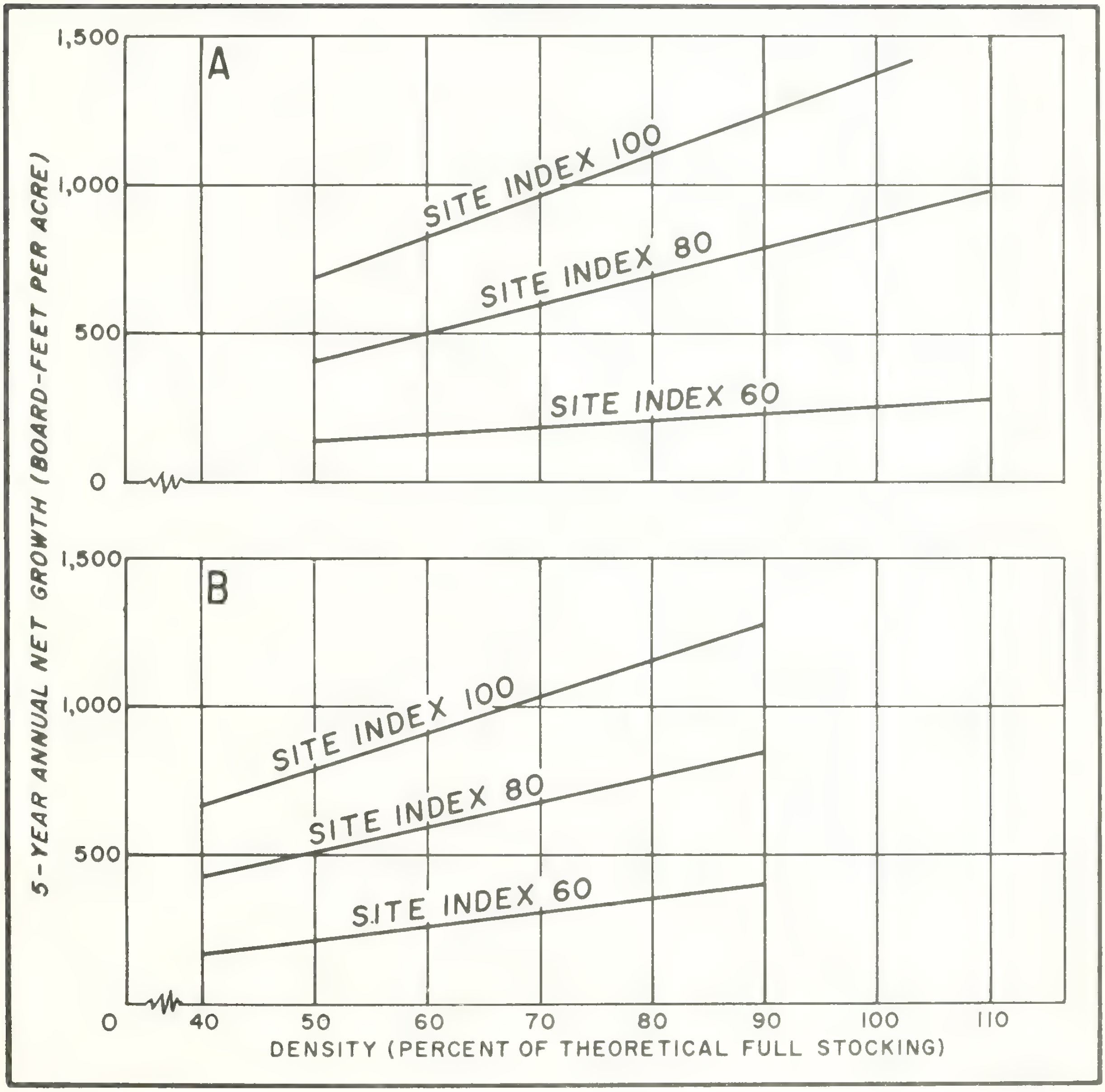

Figure 4.--Board-foot volume growth of 50-year-old stands in relation to stand density and site index. A, unthinned; B, thinned.

DISCUSSION

None of the relations found accounted for more than 40 percent of the variation in growth. The large, unaccountable variation may be related to the effect of mortality on net growth and the short growth period of 5 years. On small plots, net growth is greatly affected by the death of only a few trees because their entire volume is subtracted from the growth of the live trees in the net growth computation. Mortality occurred in the plots in this study, but it could not be taken into account because trees were not permanently marked when first measured and the dead trees could not be identified. The remeasurements were made by the progressive azimuth method, which will permit the identification of individual trees in the future so that mortality can be taken into account.

The second factor, which applies only to the thinned plots, is that 5 years is probably not enough time for the growth of the thinned stand to fully reflect the increased growing space. Stands that were reduced from a high initial density to a comparatively low density were probably especially slow to respond. However, this effect was not significant in these data when expressed as the reduction in density.

In young stands on poor sites, the decrease in volume growth per acre with increasing density is probably due mainly to slow growth of individual stems and mortality, which are expressions of the inability of the site to support the heavy stocking. However, an additional factor may be the difference in the diameter limits for density percent and volume growth. Density percent is based on all stems larger than 0.5 inch d.b.h., while cubic-foot and board-foot volumes begin at 4.6 and 9.6 inches, respectively. Because of the effect of stand density on diameter growth, ingrowth into volume size classes occurs at a later age in dense stands than in lighter stands. Thus, at certain young ages, measured growth would be less in denser stands because fewer trees contribute to volume growth. The period of fast ingrowth is also earlier on good sites than on poor sites. Apparently 20 years, the lower age limit in this study, is within the period of fast ingrowth for 60- and 80-foot sites but beyond that period for 100-foot sites (fig. 2A). The magnitude of this effect on cubic-foot volume growth can be determined in future analyses by extending the volume table to smaller diameters and including the small stems in the growth determinations. The inclusion of smaller stems is not, of course, appropriate in board-foot volumes.

Thus, because of the low correlations obtained, the optimum densities and growth rates for various sites and ages cannot yet be specified. Nevertheless, the indications that the optimum density is lower on poor than on good sites are probably correct. Gruschow and Evans [3] combined data

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[3] Gruschow, G. F., and Evans, T. C. The relation of cubic-foot volume growth to stand density in young slash pine stands. Publication pending in Forest Science. 1958.

from a number of earlier studies and found that the curves of cubic-foot volume growth culminated at low densities on poor sites, and at higher densities on better sites in 10- and 20-year-old natural slash pine stands. McClay (4) also found that the curve of cubic-foot volume growth culminated at a higher residual basal area on 80-foot than on 70-foot sites in partially cut 25- to 35-year-old loblolly pine stands. In Germany, Assman (1) reviewed data from many years of thinning and concluded that optimum stocking increased with site quality. But after summarizing data from many thinnings of beech and Norway spruce in Denmark, Möller (5) believed that 50 percent of the maximum possible stocking was best on all sites. These divergent opinions in Europe will undoubtedly be reconciled in time, but most of the evidence to date indicates that optimum density varies with site quality.

No curves were apparent in this study. This failure to show optimum densities may have been due to the limited range of densities sampled. To correct this condition, additional plots were thinned at the beginning of the second 5-year period, extending the range of residual densities to a very low level. With a wider range of residual densities, the chance of determining the optimum level should be much better.

SUMMARY

In order to determine the relations of growth, variously expressed, to the age, site index, and density of thinned and unthinned, even-aged loblolly pine stands, 153 circular $\frac{1}{4}$-acre plots were selected in 20- to 60-year-old stands of a wide range in site index and density. About 35 percent of these plots were thinned to a range of residual densities.

Cubic-foot volume growth was found to be significantly related to age, site index, and density of unthinned stands, but only site index and residual density were significant factors in the growth of thinned stands. However, age will probably be important in thinned stands in the future as they are maintained at the prescribed densities. Board-foot volume growth was significantly related to age, site index, and density in both thinned and unthinned stands.

In young stands, volume growth increased with increasing density on good sites but decreased with increasing density on poor sites, indicating that the optimum density for growth was near the lower end of the sampled density range on poor sites and near the upper end of the range on good sites. In older stands, volume growth increased with increasing density on all sites, but not so much on poor sites as on good sites. Thus, the optimum density for volume growth increases with age of stand on poor sites, while good sites will support a high density throughout the rotation.

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Silvical Characteristics of Loblolly Pine

by

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Silvical Characteristics of Loblolly Pine

(Pinus taeda L.)

by

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Because of its wide range, its occurrence in pure stands, its abundance, and its versatility in use, loblolly pine (Pinus taeda) is the principal commercial species in the southeastern United States (fig. 1). It grows in the Coastal Plain and Piedmont from central Maryland and Delaware south to central Florida and west to eastern Texas (fig. 2) (72). It does not grow in the Mississippi River bottoms and is scarce in the deep, coarse sands of the lower Gulf Coastal Plain and sandhills of North and South Carolina.

HABITAT CONDITIONS

CLIMATIC

The climate of the loblolly pine range is humid, with long, hot summers and mild winters. Average annual rainfall varies from 40 to 60 inches per year; it is least in Maryland and Delaware and at the western end of the range in east Texas (124). Along the Gulf Coast it averages 60 inches. Summer is usually the wettest season and autumn the driest along the mid-Atlantic Coast. In the western portion of the range, rainfall is more uniformly distributed through the year, but summer droughts occur often enough to be a serious obstacle to natural regeneration and planting of the species.

The frost-free period lasts from 6 months in the North to 10 months in the South. July temperatures average over 75° F. and frequently exceed 100°; January temperatures average 36° to 63° and occasionally go down to -10° in the northern and western portions of the range.

The distribution of loblolly pine is associated with the average winter temperature, and the frequency and intensity of both winter and summer rainfall (57). During both winter and summer, the area within the range of loblolly pine has a greater number of days with rain and a greater frequency of effective amounts of rain (more than 0.50 inch) than the area immediately outside the range. The area inside also has a higher average temperature in winter. In spring and autumn, the weather inside and outside the range is more nearly the same. The main factor limiting northern extension of the species is probably temperature, but the western extension is probably limited by precipitation. Low air temperatures damage aerial portions, and low soil temperatures retard water absorption more in loblolly pine than in native northern species (65). Damage by snow and sleet, which is less frequent within the range, may also be a factor limiting the northern extension.

Figure 1.--Mature loblolly pine tree in the Crossett Experimental Forest, Crossett, Arkansas.

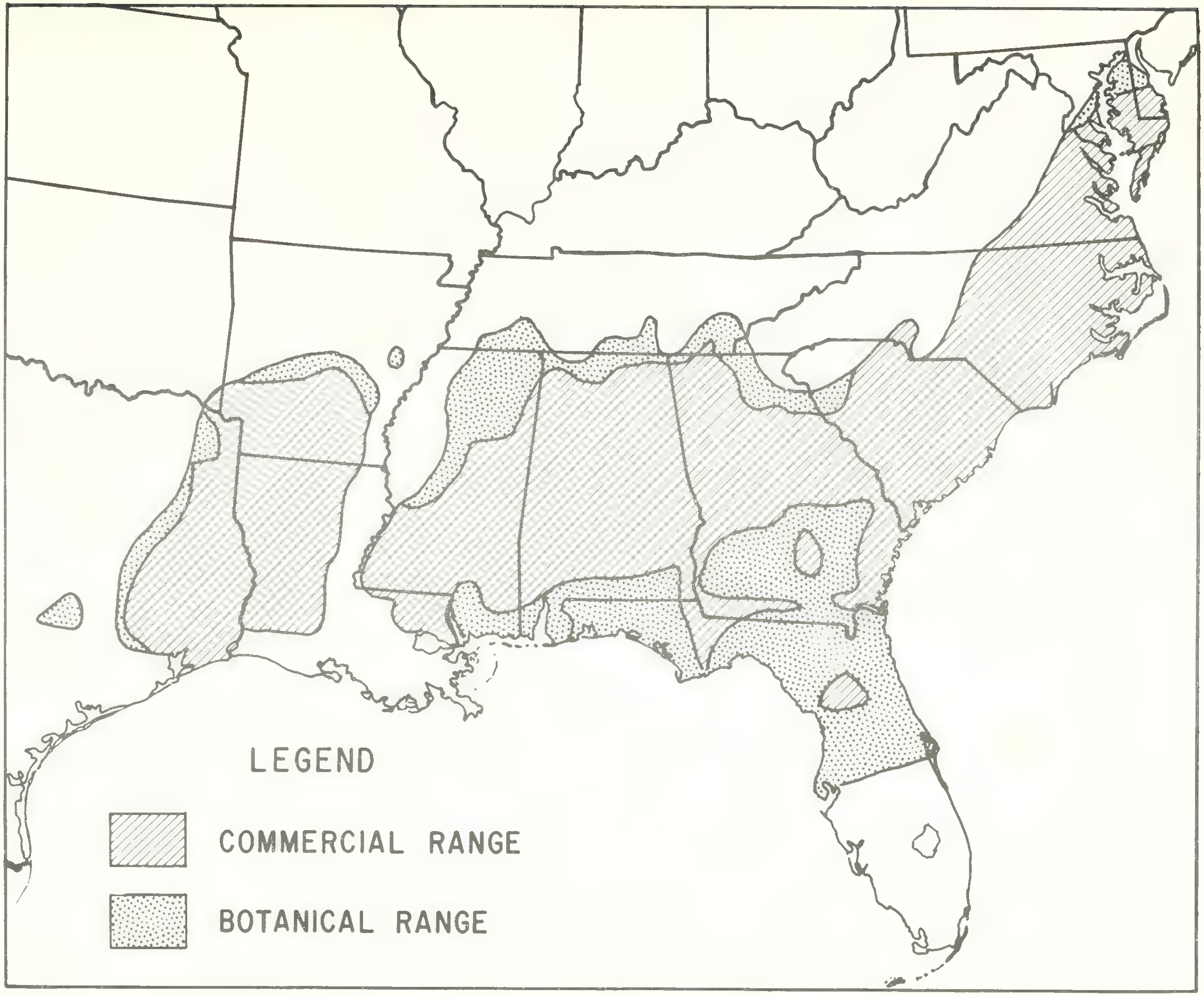


Figure 2.--Botanical and commercial range of loblolly pine.

EDAPHIC

Loblolly pine occurs on a wide variety of soils, from the flat, poorly drained, ground-water podzols of the lower Coastal Plain to the old residual soils of the upper Piedmont. It grows best in soils with poor surface drainage, a deep surface layer, and a firm subsoil (48, 150).

Such soils are common in the lower Coastal Plain and in the flood plains of the larger rivers. Prominent examples are the Coxville and Bladen series; with deep surface layers these soils have a site index for loblolly of 90 to 95 feet (48). In the same category is the Elkton series: poorly drained, very plastic soils which have an average site index of 95 feet. Most productive are the river bottom or terrace soils, notably the Roanoke series in the east and the Ocklockonee in the west; these are fairly heavy soils that have site indices of over 100 feet (24, 48). In the Coastal Plain, the productivity of soils decreases with improvement in surface drainage. The presence of a hardpan within the root profile, as in the Leon series, drastically reduces the productivity. Deep, excessively drained sands are also very low in site quality (24) unless the water table lies within reach of the tree roots; with high water tables sands may have site indices of 90 to 100 feet.

In the inland and Piedmont regions, where surface drainage is well-developed, the physical characteristics of the soil, rather than drainage, determine the availability of moisture, and uneroded soils with a deep surface layer and a friable subsoil are best (36). Common in this category are soils of the Durham, Georgeville, Appling, Cecil, Davidson, and Lloyd series, which have site indices of 80 to 100 feet when not eroded. The least productive are eroded soils with a very plastic subsoil. Iredell, Orange, and Whitestore (red phase) series fall in this group; they are practically worthless when the A horizon is gone, with site indices of less than 40 feet.

PHYSIOGRAPHIC

The range of loblolly pine extends over two main physiographic regions, the Coastal Plain and the Piedmont. The Coastal Plain is generally very flat near the coast but becomes rolling and even sharply hilly in the inland reaches with elevations ranging up to 1,000 feet in Georgia. Topography in the Piedmont is more rolling than in the Coastal Plain, with highly developed drainage patterns and generally heavier soils. Elevations range up to 1,500 feet. In northern Alabama and Georgia, loblolly pine grows at elevations up to and over 2,000 feet.

The rougher topography of the Piedmont results in greater variations in site than in the Coastal Plain. Loblolly pine site indices generally increase from ridge tops to bottoms but this variation seems to be related to soil differences rather than to slope position or steepness (35). Soil features that determine site quality, such as surface soil thickness and subsoil consistency, are loosely correlated with topography, but past land use, differences in soil parent material, and other factors also affect soil profile development and cause variations in site quality independent of topography.

Because of plentiful rainfall, rolling topography, and soil physical characteristics, the upland soils of the Piedmont and many sections of the upper Coastal Plain are subject to moderate to severe sheet and gully erosion when exposed and unprotected. The loss of surface layers in the past has undoubtedly contributed to the prevailing poor site quality of upland soils in the region (39).

BIOTIC

Pure loblolly pine stands are widespread throughout the range where moisture is comparatively plentiful (fig. 3). In general, the main associate is sweetgum (Liquidambar styraciflua), but on well-drained sites shortleaf pine (Pinus echinata), southern red oak (Quercus falcata), post oak (Quercus stellata), and blackjack oak (Quercus marilandica) are frequently found with it. On poorly drained sites black tupelo (Nyssa sylvatica), water oak (Quercus nigra), yellow-poplar (Liriodendron tulipifera), and pond pine (Pinus serotina), and in the far south slash pine (Pinus elliottii) and laurel oak (Quercus laurifolia), usually occur in loblolly pine stands (113).

In east Texas, southern Arkansas, Louisiana, and to a lesser extent in other states, mixtures of loblolly pine and shortleaf pine occur, with shortleaf pine predominating on the drier ridges and loblolly pine on the wetter sites. Commonly associated with these species are sweetgum, black tupelo, hickories (Carya spp.), southern red oak, scarlet oak (Quercus coccinea), black oak (Quercus velutina), white oak (Quercus alba), post oak, and minor species.

Loblolly pine also grows in mixtures with hardwoods throughout its range. On wet sites sweetbay (Magnolia virginiana), redbay (Persea borbonia), black tupelo, swamp tupelo (Nyssa sylvatica var. biflora), and sweetgum are prominent in the hardwood component; water oak, laurel oak, willow oak (Quercus phellos), red maple (Acer rubrum), white ash (Fraxinus americana), green ash (Fraxinus pennsylvanica), and American elm (Ulmus americana) are frequently present. On drier sites southern red oak, white oak, northern red oak (Quercus rubra), hickories, common persimmon (Diospyros virginiana), and scarlet oak are the most common hardwoods, and shortleaf and longleaf pine (Pinus palustris) are frequent associates.

In the Piedmont, and in the Coastal Plain of northern Virginia and Maryland, loblolly pine also occurs with Virginia pine (Pinus virginiana). In northern Mississippi, Alabama, and in Tennessee it is a minor associate in the eastern redcedar-hardwood type. On moist sites, loblolly is found in the longleaf pine type, the longleaf pine-slash pine type, and in the slash pine-hardwood type. In the flood plains of major rivers it is a minor associate in the swamp chestnut oak-cherrybark oak type. On moist lower slopes in the Atlantic Coastal Plain it is an important element in the sweetgum-yellow-poplar type. In bays, ponds, swamps, and marshes of the Coastal Plain it is a common associate in the pond pine type, the cabbage palmetto-slash pine type, and in the sweetbay-swamp tupelo-red maple type (113).

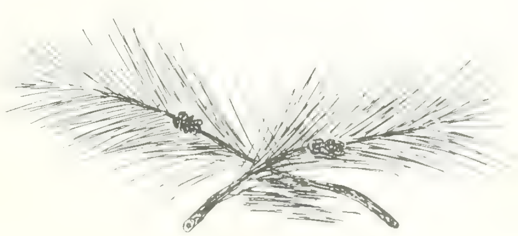
Figure 3.--Pure, even-aged stand of loblolly pine 50 years old, near Crossett, Arkansas.

Because of the wide range of sites and the numerous types in which loblolly occurs, a great variety of lesser vegetation may be found in association with it and a list of even the most common would be quite lengthy. Worthy of mention are waxmyrtle (Myrica cerifera), pepperbush (Clethra alnifolia), gallberry (Ilex glabra), viburnums (Viburnum spp.), and a great variety of ericaceous shrubs.

In the natural state, mycorrhizae usually occur on loblolly pine. Infection by several species of fungi causes proliferation of the short roots, characterized by repeated dichotomous branching. This proliferation and the accompanying mantles of fungal hyphae greatly increase the absorbing surface, and conifers in infertile soil without mycorrhizae are very low in mineral content compared to those with mycorrhizae. Mycorrhizae apparently can also supply carbohydrates from the soil, although they seem primarily dependent on those in the plant (148). They also supply nitrogen compounds, and may be able to supply vitamins. Among the fungi capable of producing mycorrhizae in loblolly pine, the following have been identified (42, 55): Boletus granulatus, Boletus exinus, Boletus brevipes, Boletus chromapes, Boletus subluteus, Boletinus pictus, Cantharellus cibarius, Cenococcum graniforme, Russula lepida, and Amanita muscaria.

Few of the animals that live within the range of loblolly pine are associated with it by a closer tie than the accident of location. Probably the most noteworthy is the red-cockaded woodpecker (Dryobates borealis) (115). This bird invariably digs its nesting cavity in a living pine tree with red heart (Fomes pini). When the cavity is finished, the bird pecks the bark all around the entrance hole, causing a heavy flow of pitch. The surface around the entrance hole thus becomes very sticky, presumably keeping out intruders. Among other birds frequently found in pine forests in the South are the brown-headed nuthatch (Sitta pusilla), the pine-woods sparrow (Peucaea aestivales aestivales), the southern pine finch (Peucaea aestivales bachmani), the pine warbler (Dendroica vigorsi), and the prairie warbler (Dendroica discolor) (115).

Four-footed animals are scarce in full stands, but after clear cutting, rodent populations increase rapidly. White-footed mice and red mice (Peromyscus spp.), harvest mice (Reithrodontomys humulis), pine mice (Microtus pennsylvanicus), cottonrats (Sigmodon hispidus), and short-tailed shrews (Blarina brevicauda) are common in cutover areas in eastern North Carolina (121). Gray squirrels (Sciurus caroliniensis) are fond of pine seed and begin to shell out cones in late summer, as soon as the seeds are well filled.



LIFE HISTORY OF THE SPECIES

SEEDING HABITS

Flowering and fruiting.--The development of loblolly pine seed requires nearly three growing seasons from the time of flower bud initiation. Flower buds are formed during midsummer, some time after the middle of June, but do not become visible until early autumn. Staminate flower buds can be seen in the South Atlantic Coastal Plain during October as small knobs around the base of vegetative buds. Later, some vegetative buds develop pointed swellings near the apex, which are pistillate flower buds. These flower buds grow rapidly in late winter and for a short time before flowering the staminate buds are very prominent.

Vegetative growth begins about March 1 in the Gulf States and about 6 weeks later near the North Carolina-Virginia boundary (44). Flowers mature and pollen cast begins about 10 days later (131). The staminate flowers are long, yellow catkins, and the pistillate flowers are small, pink or red strobili. Pollination lasts 7 to 10 days. Staminate flowers usually are the most plentiful and are borne all over the crown, while pistillate flowers tend to be concentrated in the upper portions of the crown. On the same tree, staminate flowers tend to mature before pistillate flowers (128). Thus, pollination depends largely on pollen from neighboring trees and may be inhibited if trees shed pollen at different times or are too far apart. In general, pine pollen is not carried in effective quantities farther than 300 feet, and most falls much closer to the source (146).

Within the pistillate strobili the growing pollen tubes do not reach the embryo sac to fertilize the egg cells until late the following spring. By that time, the strobili have become conelets one-half to three-fourths of an inch long. Growth of cones and seed is rapid during the second season, after fertilization occurs.

Cones mature and seed ripens usually during the early part of October. Time of seed ripening does not appear to vary greatly with latitude (44). Individual cones may contain from less than 20 to more than 200 seeds, sound and defective (131).[1/] The percentage sound may vary from about 15 percent up to nearly 100 percent. In southeastern Virginia, the average number of sound seeds per cone varied from 30 in stands averaging only 1 cone per tree up to 110 in stands averaging 150 cones per tree.[2/] The over-all average was 57 sound seeds per cone.

The seeds vary in size from 16,000 to 25,000 per pound and average 18,400 per pound (126).

1/ Records of the Tidewater Forest Research Center, Franklin, Virginia, 1952.

2/ Wenger, K. F. Seed tree stimulation study. 1951. (Report on file, Southeast. Forest Expt. Sta.)

Seed production.--Individual loblolly pine trees occasionally produce cones and viable seed at less than 10 years of age. Pistillate flowers have been observed on 5-year-old trees, staminate flowers on 6-year-old trees (106), and viable seed have been obtained from 9-year-old trees (132). But appreciable quantities of seed are not produced until much later. Seed production of dominant and codominant trees in undisturbed, even-aged stands increases gradually until the trees are 30 to 50 years old and 12 inches or more in diameter (99). It then increases rapidly until the full potential is attained. However, the viability of seed from young trees just beginning to bear is as high as that of seed from older trees (131).

Although loblolly pine stands are capable of heavy seed production to advanced ages, seed crops fluctuate widely from negligible amounts in some years to nearly a million seeds per acre in other years. Seed crops of a 70-year-old stand in North Carolina Piedmont varied from 18,000 to nearly 300,000 seed per acre during 13 years from 1936 to 1948 (101). Seed production tends to be better in the coastal portions than in the inland portions of the loblolly pine range (128), and annual seed crops of one 95-year-old and two 145-year-old stands in northeastern North Carolina ranged from 50,000 to 832,000 seed per acre from 1947 to 1954. A partially cut 35- to 45-year-old stand in coastal South Carolina produced 1.4 million seeds per acre in 1955, which is apparently the greatest seedfall recorded in loblolly pine up to that year (77).

The annual fluctuations in seed crops depend mainly on weather and the physiological status of the trees at the time of flower bud formation. In the three stands in northeastern North Carolina, the size of seed crop was positively correlated with the May-to-July rainfall of 2 years earlier and negatively correlated with the size of the seed crop 2 years earlier (142).

Although conditions may favor a heavy set of flower buds, many agencies may reduce or destroy the cone crop before maturity. Flowers may be destroyed by subfreezing temperatures, heavy rain, hail, or strong winds, or rainy weather may inhibit or prevent pollination. Drought may retard development, and insects damage both cones and seed.

Cone damage varies from year to year, usually amounting to 10 to 40 percent but may often be more or less in any given locality (63). Cone losses on individual seed trees in southeastern Virginia, caused mainly by insects, varied from 2 to 100 percent in one year and from 4 to 71 percent in the following year. Losses were greater in small crops than in large crops, and trees that sustained heavy losses in one year also had heavy losses in the next year. Most of the insect damage probably is caused by the larvae of a small moth, *Dioryctria amatella* (63), but cone beetles, mainly *Conophthorus taedae*, may also cause appreciable losses (40). Another small moth, *Laspeyresia toreuta*, destroys a small proportion of the individual seeds without otherwise damaging the cones (63). Insect damage tends to be higher in older stands and on better sites.

The quality of seed also varies from year to year with the size of the seed crop. In both the Piedmont and Coastal Plain of North Carolina viability ranged, on the average, from a little more than 40 percent in light crops to nearly 80 percent in heavy crops (101, 143). In individual stands, viability as low as 25 percent occurred.

Individual dominant and codominant trees in undisturbed stands may bear as many as 500 cones but most trees bear less than 100 cones. Intermediate and suppressed trees may never produce good crops. Fruitfulness apparently is hereditary to some degree, and cone crops of individual trees are closely related to past fruitfulness (45, 52, 99, 137). Cone crops are also proportional to diameter at breast height, and crown volume and crown density have been found to affect size of cone crops (53).

In the Atlantic Coastal States, cone and seed production of individual dominant and codominant trees released from competition and of stands partially cut increased 2- to 10-fold three growing seasons later (46, 99, 119, 137). Trees of larger diameter and greater past fruitfulness produced much larger crops after release than smaller or less fruitful trees. As many as 1,500 cones may develop on some trees after release but most trees bear less than 500 cones. The response to release is greater when it coincides with good seed years; in partially cut stands it seems to be proportional to the intensity of cutting. It usually persists for several succeeding crops but eventually subsides (46, 137).

The cone crop in the third succeeding fall is larger if the release cutting is done before late spring. In the South Atlantic Coastal Plain the critical period is some time during late June or July--release during or after that period is not reflected in cone crop until the fourth succeeding year. The reduction in transpiration accompanying the removal of competing trees, which is probably equal to several inches of rain, may be the primary cause of the increase in cone crops following release (142).

Seed dissemination.--Seedfall usually begins during the early part of October and does not vary greatly with latitude (44). It reaches a peak very quickly and then declines. By January 1, 80 to 90 percent of the seed has fallen, although some continues to fall until late spring. Seedfall is hastened by dry, warm, windy weather and retarded by cool, wet weather (59). Viability of the seed is highest at the peak of the seedfall. Seed falling later is progressively lower in viability until the end of seedfall in the spring.

Although loblolly pine seed is entirely wind-disseminated, and was apparently carried 2.5 miles from the source in one case (104), it is usually not dispersed in effective quantities more than 300 feet. In strip cuttings in North Carolina, 67 percent of the seed fell within 100 feet and 85 percent fell within 200 feet of the windward uncut strip (101). In old fields, where seed dispersal was less restricted, the number of seedlings established fell below 1,000 per acre at 330 feet from the seed source, and beyond 462 feet was less than 500 per acre (83).

VEGETATIVE PROPAGATION

When 1- to 3-year-old seedlings of loblolly pine are decapitated or injured, they sprout readily from buds formed in the axils of primary needles (116, 117).[3] Older seedlings and trees do not sprout. Rooting ability is similarly confined to young seedlings. Nearly half of the cuttings from 1-year-old seedlings rooted, but only 6 percent rooted from 2-year-old seedlings, and none rooted from 3-year-old seedlings (49). Rooting by air-layering has been somewhat more successful. Six of ten $2\frac{1}{2}$-year-old seedlings developed roots in air-layers in one test (152), and good results were obtained with 3- and 5-year-old seedlings in another (20). In the latter test, results were poorer with older trees but air-layers even from 60-year-old trees developed a few roots.

Loblolly pine has been successfully grafted by several methods. In very limited tests, one-half or more soft-tissue grafts were successful (151). These included loblolly scions on loblolly and shortleaf stocks and shortleaf and slash scions on loblolly stocks. Side grafts of loblolly on loblolly were completely successful when made in April and somewhat less successful when made in February and March (31). Wedge grafts were least successful.

SEEDLING DEVELOPMENT

Establishment.--Birds and rodents probably eat appreciable amounts of seed between seedfall and germination, but apparently not enough to hinder natural regeneration (143) except in poor seed years. Bob-white quail (*Colinus virginianus*) in eastern Maryland have been found to eat pine seed in preference to wild and cultivated leguminous seed (145). However, as many as 89 percent of sound seeds may fail to germinate (100, 126). Further losses occur because of limited moisture related to seedbed conditions and the failure of the radicle of germinating seeds to penetrate hard soil surfaces and deep litter (51, 100).

Moisture remains the most important factor in survival throughout the first growing season. The greatest mortality occurs shortly after germination (47) and tends to be higher in lighter soils. Droughts after midsummer, when soil moisture is already quite low, may also cause heavy mortality, particularly where competing vegetation is abundant. A study in Arkansas showed that most new seedlings established on third-year and older seedbeds had disappeared by the following year (86), probably because of competition from hardwood brush.

Losses from these various causes are reflected in the large number of sound seeds needed to establish a seedling, even on the best seedbed. In northeastern North Carolina, the number of sound seeds needed to establish 1 seedling on fresh seedbeds averaged 9 on exposed mineral soil, 15 on burned soil surfaces, and 40 on undisturbed litter and logging slash (118). A similar effect of seedbed condition on seedling establishment was observed in southeastern Arkansas (51). Thus, much larger amounts of seed are required for

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3/ Little, S. Official correspondence, Southeast. Forest Expt. Sta. 1957.

satisfactory reproduction on undisturbed litter than on mineral soil. Favorable seedbed conditions disappear rapidly, and about four times as many seeds are needed on second-year as on first-year seedbeds to establish one seedling (86, 120, 141). By the third year, initially favorable seedbeds have become nearly as unfavorable as undisturbed litter.

Natural regeneration of loblolly pine thus depends on adequate amounts of seed in the first year after logging or seedbed preparation (120). In small ownerships adequate seed can often be obtained by postponing harvest cutting until after seedfall. The seed-tree method gives the greatest control of the seed supply through variations in the numbers of seed trees (140), but adequate seed can also be obtained from seed strips. Seed is usually more plentiful in stands managed by the selection method because of the large number of seed-bearing trees and the stimulation of seed production by repeated cutting.

Where the bulk of a well-stocked stand is cut, tractor logging exposes mineral soil on about 50 percent of the logged area, which is usually sufficient for satisfactory regeneration in good seed years (118). In mediocre seed years, however, or with less effective logging methods, additional site preparation is essential. Scarification with a bush-and-bog diskharrow or burning before or after logging have been successful (23, 30, 73) and will usually compensate for the lower seed supply in mediocre seed years. Periodic winter fires throughout the rotation, with the last fire just before the harvest, or several annual summer fires before the harvest, have also been tested with considerable success (76, 105). The effects of site preparation on the amount of hardwood brush persist for several years, so that a greater percentage of established seedlings become dominant (75, 143).

In poor seed years, the number of seed trees needed becomes prohibitively large, even with intensive seedbed preparation, unless the seed trees are selected and released from competition 3 to 5 years before the harvest cut. In the South Atlantic Coastal Plain, released trees produce enough seed for adequate regeneration even in poor seed years (140). Since heavy cone crops are evident a year before maturity (119) and are usually followed by a poor crop 2 years later, poor seed years apparently can be predicted far enough in advance so that trees can be released in time to supply increased amounts of seed in the poor year (142).

Early growth.--The resumption of growth in the spring is mainly a response to rising air temperature but is also influenced by soil temperature (64).4/ It usually occurs before the date of the last killing frost (66), in late March or early April in the northerly portions and about a month earlier in the southerly portions of the range. Twenty percent or more of the year's height growth occurs each month from April to August and is usually at least 80 percent complete by July 1 in all parts of the range (66, 103, 144). Vigorous seedlings make several surges of height growth, normally three, during a growing season; the first is the longest and the last is usually very short (138).

4/ Hahn, V. W. The effect of soil and air temperatures on the resumption of growth of tree seedlings in the spring. 1942. (Unpublished Master's thesis, Duke University, Department of Botany.)

Best growth occurs when night temperatures are 12° to 13° C. lower than day temperatures (70). Thus, slowing of height growth in midsummer may be due in part to high night temperatures. High night temperatures may also be an important factor in the generally slower growth of loblolly pine along the Gulf Coast. Height growth ends in late summer, before air temperatures become unfavorable and apparently in response to shorter periods of daylight (64). Foliage is usually retained till the end of the second growing season, although it may be cast earlier if infected by the needle-blight fungi, chiefly *Lophodermium pinastri* and *Hypoderma lethale* (9, 11).

Roots of loblolly pine grow at all times of the year (103, 123). Most root growth occurs in spring (April and May), and in late summer and early fall; least root growth occurs in winter and midsummer. Growth in winter is limited by low temperatures, none having been observed at less than 53° F. (123). Growth in summer is limited by low soil moisture and high temperatures. Optimum temperature is 77° F. and root growth ceases between 86° and 95° (103).

During the first 5 to 10 years, height growth of vigorous loblolly pine seedlings follows a rising trend, and may average 2.5 feet per year (12, 127, 138). Under favorable conditions, seedlings may reach 2 feet in height in the first year but the average first-year height is about 4 inches (102). In North Carolina, first-year seedling heights varied with soil surface conditions; the tallest 10 percent of seedlings present exceeded 11 inches in severely burned areas, 7 inches on bare soil or disturbed litter, and 5 inches in undisturbed litter, slash piles, and lightly burned spots. The better growth in severely burned areas was still evident at 5 years (138). Light shade apparently is beneficial in the first year (8); thereafter it is not.

In the Coastal Plain of North Carolina, seedlings grew faster in sandy loams with friable subsoils than in silt loams with plastic subsoils (139). Seedlings on the better soils also had larger crowns. In a study of potted seedlings, growth was least in sand and best in a silty clay (136). Loosening of the soil by disking apparently aids height growth during the early years (139).

Height growth of loblolly pine seedlings is inversely related to the stocking of larger trees within a 30-foot radius and directly related to level of shade (12, 29). In Arkansas, heights of 5-year-old seedlings ranged from 0.8 foot under a full canopy to 10.0 feet in large openings (127).[5] In 8- to 15-foot openings, seedlings were 2.6 feet tall in 5 years; this rate of growth was judged to be adequate for survival, but in smaller openings growth was less. In Georgia, the average seedling was 0.7 foot shorter for every 10-foot lower shade level (12). If the over-topping trees are hardwoods, seedling growth is still less--in Arkansas seedlings were 0.14 foot shorter for every 10 percent increase in the basal area of hardwood cover.[5] Seedlings growing beneath larger hardwood trees invariably die if they are not released. In a

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5/ Wahlenberg, W. G. Effect of overwood on survival and development of loblolly pine seedlings in southern Arkansas. 1946. (South. Forest Expt. Sta. office report.)

study in Louisiana, no seedling established under hardwood shade survived for more than 19 years, and the average period of survival was 5.27 years (29). Seedlings that grow less than 6 inches annually in height probably will not survive (29, 127, 138).

Low-level competition from hardwood shrubs and sprouts reduces height growth and is often fatal to loblolly pine seedlings. Approximately 80 percent of overtopped 3-year-old and older seedlings and 15 to 40 percent of seedlings with side competition do not survive (109, 138). Height growth and crown expansion of hardwood sprouts is rapid during the first 3 years and much slower thereafter (13, 138). Consequently, seedlings that are not overtopped at 3 years or later have a good chance of outgrowing the competing hardwoods.

These variations in seedling growth are responses mainly to differences in light and soil moisture caused by competing hardwoods. The maximum rate of photosynthesis is greater in hardwoods than in loblolly pine, and the hardwoods reach their maximum rate at one-third or less of full sunlight (61, 68). Pine reaches its maximum rate at that light intensity only in the first year, because the primary needles are so arranged that they shade each other very little (8). But the arrangement of secondary needles on older seedlings results in much mutual shading (67) and photosynthesis proceeds in proportion to light intensity, reaching the maximum rate only in full sunlight (61, 68). Low light intensity also reduces photosynthesis through its effect on water absorption. Pine root systems are smaller than hardwood root systems under full light but the difference becomes much greater under partial light (34, 61, 62, 136). Thus, absorption is retarded under partial light, even when soil moisture is ample, and moisture stress in the seedlings is increased, which reduces the photosynthetic rate. When soil moisture is also low, the moisture stress in the seedlings is still greater. Thus, photosynthesis is reduced more rapidly in pine than in hardwoods by decreasing soil moisture (7, 59).

Since low light intensity and low soil moisture usually occur together under natural conditions, loblolly pine suffers much more than the hardwoods from competition. In the first year, moisture is evidently the more important factor; in a study in North Carolina, pine seedlings in their first year did not respond to increased light at low moisture levels (47). After the first year, light is the more important factor; loblolly pine seedlings in the shade do not develop root systems large enough to supply the moisture needed for survival. With ample light, root systems are larger and supply the water and nutrients needed for survival even with soil moisture as low as that within a stand (69, 95). However, either deficient light or deficient soil moisture will retard growth; if both are deficient the seedlings usually die (60).

Too much water may also be detrimental to seedling growth and survival, although loblolly pine can endure prolonged flooding of the roots better than pond pine, its wet-land associate. One test of various periods of flooding showed that at least 10 months of continuous flooding with standing water was needed to permanently injure roots of loblolly pine seedlings (58). Pond pine showed permanent injury by failure to make normal height growth during

periodic drying after 3 months of continuous flooding. Another test showed that loblolly pine could endure flooding for a 50-percent longer period than pond pine.[6]

Growth and survival of loblolly pine seedlings are also affected by insect and disease attacks. Repeated attacks by the Nantucket pine tip moth (Rhyacionia frustrana) reduce height growth and cause crooking and forking but usually do not cause mortality. The pales weevil (Hylobius pales) and its close relatives may kill planted seedlings in large numbers in recently cut or burned areas but have not been important in natural reproduction. The red-headed pine sawfly (Neodiprion lecontei) and the pine webworm (Tetralopha robustella) can cause mortality by defoliation and occasionally cause large losses in limited localities. In many localities west of the Mississippi the Texas leaf-cutting ant (Atta texana) is a serious pest on natural and planted seedlings, and control measures are necessary.

The most common disease is fusiform rust (Cronartium fusiforme). It causes lethal stem and branch cankers and has oak as an alternate host. The brown spot needle disease (Scirrhia acicola) is common in some areas and heavy infections probably check growth (10).

SAPLING STAGE TO MATURITY

Growth and yield.--Pure, even-aged stands of loblolly pine vary greatly in growth and yield in response to differences in site quality. Individual trees in particularly favorable locations may attain diameters of 50 to 60 inches and heights of 150 feet at advanced ages (2). The largest recorded loblolly pine presently in existence is located in Dinwiddie County, Virginia, and is 63 inches d.b.h. and 128 feet tall (1); another in Hertford County, North Carolina, is 54 inches d.b.h. and 151 feet tall. The average tree is much smaller. Sizes attained by average trees in the dominant portion of well-stocked, unmanaged natural stands are shown in the tabulation below (125). Trees in managed stands would be considerably larger in d.b.h. at the same ages.

	Site Index 60 feet		Site Index 90 feet		Site Index 120 feet	
Age (Years)	D.b.h. (Inches)	Height (Feet)	D.b.h. (Inches)	Height (Feet)	D.b.h. (Inches)	Height (Feet)
20	4.6	32	6.9	48	8.5	64
30	6.6	45	9.6	67	11.9	89
40	8.1	54	11.7	81	14.6	108
50	9.4	60	13.6	90	16.8	120
60	10.4	64	15.0	96	18.6	128

6/ Gaiser, R. N. The growth of loblolly and pond pine seedlings under differing conditions of soil flooding. 1947. (Unpublished manuscript, Duke University, Department of Botany.)

Because of its economic importance and wide range, several yield and growth studies of well-stocked natural stands of loblolly pine have been made (2, 79, 85, 125). One of these sampled the entire range of the species and indicated a maximum mean annual growth rate of 1,300 board-feet per acre (Int. 1/8-inch) in trees 6.6 inches d.b.h. and larger at 45 years, the age of culmination of mean annual increment for stands of 120-foot site index (125). On 60-foot sites the maximum rate was 318 board-feet per acre per year. Data from permanent sample plots in the Atlantic Coastal States indicated a possible current annual growth rate of 1,500 to 2,000 board-feet per acre (Int. 1/4-inch) in trees 9.6 inches d.b.h. and larger on the very best sites at age 55. Yields at 60 years in trees 6.6 inches d.b.h. and larger range from 19,000 board-feet per acre (Int. 1/8-inch) in well-stocked stands of 60-foot site index up to 73,000 board-feet per acre in stands of 120-foot site index (125).

Mean annual cubic-foot growth in trees 1.6 inches d.b.h. and larger ranges from 76 cubic feet per acre at 35 years (culmination of MAI) on a 60-foot site to 204 cubic feet per acre on a 120-foot site (125). Cubic-foot yields at 60 years in well-stocked stands vary from 2,400 cubic feet per acre on the poorest sites to nearly 12,000 cubic feet per acre on the best sites (79).

Mean annual growth in standard cords in trees 3.6 inches d.b.h. and larger ranges from 0.88 cord per acre per year at 40 years in well-stocked stands of 60-foot site index up to 2.37 cords per acre per year at 35 years on 120-foot sites (128). Yields of well-stocked stands at 60 years range from 46 cords per acre on 60-foot sites to 121 cords per acre on 120-foot sites.

In addition to varying with age and site quality, volume growth is strongly related to stand density, increasing with density up to a maximum that is higher on good sites than on poor sites (80). The volume growth of thinned stands also varies with age, site quality, and residual stocking. Recent studies by the Southeastern Forest Experiment Station suggest that the growth of thinned and unthinned stands does not differ greatly after one thinning when age, site quality, and stocking are equal. Although information presently available is insufficient to compare yields of managed and unmanaged stands, stands maintained at their optimum density by thinning throughout the rotation will undoubtedly produce more wood because most moribund trees will be salvaged and the residual trees will grow faster.

Reaction to competition.--Loblolly pine is classed as an intolerant species, of the same degree of tolerance as shortleaf pine and Virginia pine, less tolerant than the oaks, and more tolerant than slash pine and longleaf pine (3).

The more tolerant hardwoods readily become established in the understory of loblolly pine stands, and on uplands throughout the range of loblolly pine the progress of plant succession is toward a hardwood, oak-hickory climax (94). The succession can be most clearly seen in old-field stands (fig. 4). Light-seeded and intolerant hardwood species, such as sweetgum, red maple, yellow-poplar, blackgum, and waxmyrtle are early invaders. Somewhat later the components of the climax, oaks and hickories, appear.

Figure 4.--Old-field stand of loblolly pine in the Kisatchie National Forest, Louisiana. The understory of small hardwoods has developed since the stand was established.

They increase in size and number as the pine stand matures (5, 94) and replace pines in the overstory as the stand disintegrates between 100 and 300 years of age. Cutting of the pine stand without provision for reestablishment hastens the process, which accounts for the increase in hardwood types throughout the loblolly pine range. Fires during the dormant season have little effect on the succession because the hardwoods sprout prolifically and vigorously, and even annual dormant-season fires do not reduce the hardwood crown area or number of stems (76). However, repeated fires at intervals of less than 10 years ultimately eliminate loblolly pine (30, 134). Crown fires destroy the entire stand, as may hot surface fires during the growing season (17), but pine readily becomes reestablished if a seed supply is available because the hardwoods are also killed back to the ground (93).

Because it is intolerant of shade, loblolly pine expresses dominance early, and crowns differentiate rapidly under competition on good sites. In dense stands on poor sites, expression of dominance and crown differentiation are much slower. The density of undisturbed stands approaches an equilibrium at a rate that probably varies with site quality (21). Well-stocked stands ranged from 118.7 square feet of basal area per acre for trees 4 inches in d.b.h. up to 175.4 square feet for trees 16 inches d.b.h. (114). In Arkansas, well-stocked stands tended toward a basal area of 155 square feet per acre (28).

Annual radial growth of loblolly pine is positively correlated with total rainfall from January to May and negatively correlated with temperature (33). It reaches a maximum early in the growing season (149), and is directly proportional to crown ratio (54, 71), crown length, and total height.[7] Volume growth, however, also depends on the length of the clear stem. In 26-year-old trees, cubic volume growth of the clear stem was greatest with a crown length that was 40 percent of total tree height (71).

Loblolly pine prunes itself readily at younger ages, before branches develop heartwood. The maximum contribution to main-stem growth is made by branches in the upper portion of the crown, 15 percent of tree height from the top (71). Below this point the contribution becomes progressively less, until branches halfway down the stem contribute nothing.

The increase in diameter growth after release is also directly related to crown ratio, but trees of large diameter respond less than trees of small diameter (26, 78). MacKinney (78) found that trees about 60 feet tall increased diameter growth more than shorter or taller trees after release. Thus, tall, slender trees with well-developed crowns, that is, codominants and better intermediates, respond best to release. Trees long suppressed also grow much faster in both height and diameter after release but may never attain the growth rate of trees that were never suppressed (26). Height growth

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7/ Dubow, D. A. The relationship between crown and bole length and their ratios with diameter growth in young loblolly pine plantations. 1953. (Unpublished Master's thesis, North Carolina State College, School of Forestry.)

after release apparently depends mainly on age at release, while diameter growth depends on crown size and growing space. The capacity of loblolly pine to respond to release means that noncommercial removal of competing hardwoods is usually a profitable investment (15, 112).

Mortality in loblolly pine stands is caused mainly by competition (16, 111), but fire, wind, lightning, sleet, disease, and insects may cause substantial losses. Accidental fires may completely destroy stands, but more commonly reduce growth (4) and cause stump wounds that permit the entrance of decay fungi and insects and result in pitch soaking (50). Trees in repeatedly burned areas develop greater butt swell than unburned trees (27). Large, dominant trees are more vulnerable to wind damage than smaller trees (122), and trees with large cankers caused by the southern fusiform rust break more readily than sound trees (135). Although direct losses to lightning are small, averaging only 2 trees per 100 acres per year (122), lightning-struck trees often become centers of infestations by the southern pine beetle (Dendroctonus frontalis). Other injuries and drought conditions also favor this insect and it has killed large volumes of loblolly pine throughout the range. The engraver beetles (Ips spp.) and the black turpentine beetle (Dendroctonus terebrans) may also cause serious losses under the same circumstances (84). Sleet storms bend, break, and uproot many trees and may severely damage heavily stocked stands (82, 91), particularly those made up of slender, small-crowned trees. Loblolly pine beyond the sapling stage is seldom killed by disease, but fungi cause appreciable cull in older stands. Heart rot (Fomes pini), entering through branch stubs, and butt rot (Polyporus schweinitzii), entering through fire wounds, are the most important causes of such losses (56).

After heavy partial cutting in older stands of moderate or higher density, many residual trees die from causes directly related to logging and exposure. Intermediate and suppressed trees may succumb to the drastic change in environment (22, 74). Isolated dominants and codominants, as in seed-tree stands, die at the rate of about 1 percent of the number of trees per year, mainly from wind and lightning (32, 74, 122). Logging injuries and bark-beetle attack are important causes of death in the first few years after cutting; puddling of heavy, wet soils and attendant root damage have also caused substantial losses (81). Ice damage to residual trees is negatively correlated with live-crown ratio, small-crowned spindling saplings being most vulnerable (92).

SPECIAL FEATURES

In common with other hard pines, loblolly pine is highly resinous, although less so than slash pine and longleaf pine. The constitution of the oleoresin of loblolly pine is as follows (90):

Density	0.8570^{22}
Index of refraction	$1.4675^{27.5}$
Specific rotation, degrees	+ 20.2
Turpentine yield, percent	19
Turpentine composition, percent	85 d-alpha-pinene 12 1-beta-pinene

The specific gravity of green loblolly pine wood averages 0.47 and increases from the pith outward. The trend is mainly due to age of the tree at the time the annual ring is formed and partly due to decreasing width of rings (147). Specific gravity is greatest near the base of the tree and decreases with height; and it is greater in small-crowned than in large-crowned trees (97). It also increases as the percentage of summerwood increases.

Tracheid length varies greatly from tree to tree, suggesting that it is strongly dependent on hereditary factors as well as on environmental conditions (6). Tracheid length averages 4.3 millimeters and ranges from 1.5 up to 7.0 millimeters (14). It increases sharply from the pith outward during the first 10 years and at a slower rate beyond that point; it also increases from the base of the tree upwards to middle height and decreases above that level (6).

The angle made by the fibrils (strands of cellulose that make up the tracheids) with the main axis of the tracheid is related to longitudinal stability of lumber and tearing strength of both sulfite and sulfate pulp made from the wood (98). Large fibril angles are associated with much shrinkage along the grain and lesser tearing strength of the pulp. Fibril angles in loblolly pine vary from 2 to 51 degrees, decrease from the pith outward and from the base of the tree upwards, and are smaller in narrower annual rings. Closely spaced trees with small crowns have smaller fibril angles than widely spaced, large-crowned trees.

RACES AND HYBRIDS

Distinct races of loblolly pine have not been identified and described, but definite variations in survival, growth rate, disease resistance, drought hardiness, and cold hardiness associated with seed source have been observed. In tests at several locations in the Southern and Central States, seedlings from north Alabama seed had a higher survival rate at 2 years than seedlings from Maryland and Virginia seed, while no seedlings from North Carolina and South Carolina survived (41). In other widely scattered tests in the South, seed from North Carolina and South Carolina has given better results (130).

Seedlings from seed of six different sources planted in southern Illinois showed a significantly different rate of height growth in the first year for each seed source (88). In another study, Maryland seedlings planted at a number of places throughout the south grew less in height than those from other locations, but had exceptionally well-developed fibrous roots (130).

Near Bogalusa, Louisiana, trees from a local seed source were taller, larger in d.b.h., and greater in cubic-foot volume per acre at 22 years than trees from Texas, Georgia, and Arkansas seed sources (129). In South Africa, loblolly pine trees from southern seed sources in the United States were taller at 9 years than those from northern sources, except that seedlings from Onslow County, North Carolina, were taller for their latitude, and seedlings from the Kisatchie National Forest in Louisiana and from the Crossett Experimental Forest in Arkansas were shorter (108). At Athens, Georgia, and Jasper, Texas, the variation in height growth with latitude of seed source was much less pronounced than in South Africa, but the good performance of the North Carolina strain and the poor behavior of the Louisiana and Arkansas strains showed up again (129).

Eastern strains of loblolly have shown a higher susceptibility to fusiform rust infection than western strains. In the Bogalusa plantings, 37 percent of Georgia trees were infected, while infection of other strains ranged from 4 to 6 percent. In the Jasper and Athens plantings, eastern strains had a much higher incidence of rust than western strains, but northeastern strains, from Virginia and Maryland, had very few infections in either locality (129).

Cold resistance also varies with seed source. Seedlings of Virginia, Maryland, Tennessee, and Arkansas strains in nursery beds in southern Illinois were not damaged by subfreezing temperatures, but North Carolina seedlings sustained moderate damage, and South Carolina and Mississippi seedlings sustained moderate to severe damage (89). In Maryland, seedlings from local seed were not injured by cold, but those from more southerly sources were damaged, the southern-most strain--from Louisiana--being conspicuously injured (130).

Because of its well-known adaptability to a wide range of environmental conditions, loblolly pine has been planted in many places outside its range. It has been successfully grown in Australia, New Zealand, South Africa, and in the coastal region of Uruguay; in the United States it has been grown at Placerville, California, and in parts of Tennessee, southern Illinois, southern Indiana, western Kentucky, and southern New Jersey. In Pennsylvania and Massachusetts, seedlings are winter-killed; in Ohio and southern Indiana, needles commonly show cold injury (96). Cold also injures loblolly pine in the Ozarks (110).

In the "Lost Pines" area and at the western edge of its range in east Texas, where summer rainfall is often deficient, loblolly pine is apparently more drought hardy than it is farther east. In a test in east Texas, seedlings from that locality had consistently better survival than seedlings from Louisiana, North Carolina, and Florida (154). No differences in growth among the surviving seedlings were observed, however.

Variations in the behavior of individual trees have also been traced to hereditary factors. In South Carolina, seedlings from different mother trees differed significantly in height growth and survival (87).

One natural hybrid involving loblolly pine has been identified and named. This is the hybrid known as Sonderegger pine (Pinus x sondereggeri). It is common in Louisiana, and perhaps elsewhere, in longleaf stands near a source of loblolly pine pollen (25, 43). The seed apparently comes from longleaf pine trees; hence loblolly pine is probably the male parent. Many trees with characteristics intermediate between those of shortleaf and loblolly pine, which may be hybrids, have been found in east Texas (153) and may occur wherever these two species grow in mixture. Loblolly pine flowers before shortleaf pine but early conelets of shortleaf pine may become receptive while loblolly pine pollen is still being cast; or loblolly pine flowering may occasionally be retarded by cold weather so that loblolly pine conelets might still be receptive when shortleaf pine starts pollinating. Where loblolly and pond pine are closely associated, pines with intermediate characteristics between these two species are common.

Interspecific hybrids of loblolly pine are not difficult to obtain (43) and a number of successful hybrids have been produced by controlled pollination. Some successful hybrids that have been reported are as follows (18, 19, 38, 107, 133):

Seed parent	Pollen parent
Shortleaf	Loblolly
Slash	"
Pitch	"
Longleaf	"
Loblolly	Pitch
Shortleaf x loblolly	Loblolly
Loblolly	Shortleaf
"	Slash
Shortleaf x loblolly	Loblolly x slash
Loblolly x slash	Slash
Loblolly	Sonderegger
"	Shortleaf x loblolly
Shortleaf	Shortleaf x loblolly
Shortleaf x loblolly	Loblolly x slash
Shortleaf x slash	Sonderegger
Longleaf	Sonderegger

Seedlings from a cross between loblolly pine and South Florida slash pine (Pinus elliottii var. densa) are growing at Hamilton, Georgia, and at the Southern Institute of Forest Genetics near Gulfport, Mississippi.[8] Seedlings of pond x loblolly pine are growing at the Westvaco Experimental Forest, near Georgetown, South Carolina (37).

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Drought Estimation in Southern Forest Fire Control

by

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INTRODUCTION

A simple method for gaging the intensity of drought would be valuable to men responsible for fire control in the South. They want to know when soil moisture becomes reduced to a level where fire-control difficulties are intensified--as for instance, when fires creep under lines in buried material and rekindle outside. They want to know whether normally wet areas such as branch heads and bays have become so dry that fire will sweep through the heavy fuels with increased intensity instead of being stopped, and whether fires will easily spot over plowed lines.

During extended droughts, aerial fuels become more flammable, firelines are hard to build and hard to hold, fires burn with great intensity and high rate of spread, and sometimes high-intensity fires produce convection columns that spew firebrands for long distances. As examples of what can happen during prolonged periods of little rain, in 1955 and 1956 four fires in the South each burned more than 100,000 acres. Drought conditions coupled with certain atmospheric conditions caused this excessive loss.

Type 8 and type 8-100 fire danger meters (7, 15), now in almost universal use in the East and South, were not designed to measure the deep drying of soils during droughts. To be sure, fuel moisture sticks used in connection with the meters are reliable indicators of the dryness of the thin upper layer of fuel, which is usually the first to ignite. And the Buildup Index is a measure of the moisture content of the 3 or 4 inches of fuel below the top layer. But neither of these indicators reflects soil moisture depletion during prolonged hot and rainless periods. For this reason, an attempt has been made to develop a measure of drought severity that can be used as a supplement to our present method of estimating fire danger.

This paper describes a possible approach to a system for estimating drought. It is based on the idea suggested by Thornthwaite (22) and others that the amount of water available to root systems of plants can be considered as a bank balance. Deposits to the bank are in the form of precipitation, and withdrawals in the combined form of evaporation and transpiration.

In developing the approach later described, it was necessary to consider a number of factors that might influence the rate and amount of bank deposits and withdrawals. These included the elements of weather that cause different types of forest stands to transpire at a fast or slow rate, root distribution, depth of soil profiles, water-holding capacity in soils of different texture, availability of soil moisture to root systems, and the effect of interception by tree foliage and stems on the amount of precipitation entering the soil. These factors are discussed in the first part of the paper so that the reader can better follow the reasoning that led to the development of the proposed drought indicator.

The method suggested is intended primarily for relatively flat terrain and for relatively deep inorganic soils where root development is not impeded by more or less impervious layers. However, some of the assumptions in this paper regarding soil moisture depletion and accretion may apply equally well to other soils and other areas.

There is voluminous literature on soil moisture depletion, droughts, evapotranspiration, and related subjects. Only a few references that seem particularly pertinent will be cited in this article. Lull (9) has excerpted a number of publications; and people interested in additional references will find many excellent articles in the 1955 U. S. Department of Agriculture Yearbook (23).

EVAPOTRANSPIRATION

Water loss from soils is a complex of soil, weather, and plant relations. A great deal of work has been done on the subject, but principally by those interested in the production of agricultural or orchard crops. Much less study has been made of water loss from soil covered with forest growth.

Although contradictory evidence can be found on almost every other point, it is generally agreed that water available to plants is lost from the soil largely through evaporation and transpiration. In a forest stand, transpiration is by far the most important. For the purpose of this report, both losses will be described by the commonly used term evapotranspiration and referred to as ET.

According to Thornthwaite and Hare (22), ET depends on:

1. Amount of energy supplied to the evaporating surface, principally by solar radiation

2. Removal of vapor from evaporating surface, as by wind

3. Type of vegetation and depth of root system

4. Nature of the soil and the amount of available water in the root zone

Many investigators subscribe to the concept advanced by Thornthwaite (21) that mean temperature can be used to measure ET if allowance is made for latitude, i.e., length of day. Other variables such as wind and relative humidity affect the rate of vapor removal from evaporating surfaces but apparently their effect, as well as length of day in the South, is not of sufficient magnitude to warrant inclusion in any simple estimating procedure. Therefore, in the present report, it is assumed that water available to forest stands is lost primarily through transpiration, and that the rate of loss can be estimated from mean temperature.

EFFECT OF SOIL MOISTURE CONTENT ON RATE OF TRANSPIRATION

Do forest stands--or for that matter, other types of vegetation--remove water from the soil at approximately the same rate regardless of the amount of available water? This question has an important bearing on the development of a method for estimating moisture depletion. The experts disagree.

On the one hand, Thornthwaite and Hare (22) state specifically, "...the evapotranspiration rate which diminishes as the soil dries is proportional to the water in the soil. When the soil moisture is reduced to 50 percent of capacity, the actual evapotranspiration rate will be only 50 percent of the potential rate." Taylor and Slater (20) say, "Although the plant roots take water freely from soils at field capacity, the work required to remove the water becomes progressively greater as the soil becomes drier and the forces of retention increase." According to Zahner (28), "Although there is some variation with soil type, for practical consideration it can be assumed that the rate of moisture depletion by upland pine-hardwood forests is directly proportional to the moisture content of the surface six feet of soil--the effective root zone."

On the other hand, Veihmeyer and Hendrickson (25), in writing about the irrigation of orchards, state "...soil moisture, from field capacity down to the permanent wilting percentage, is readily available to plants..." This view is supported by Wadleigh (26) "...there is evidence indicating that, for practical purposes, soil water is essentially equally available almost down to the wilting percentage." Hoover, Olson, and Greene (6) found that in an 11-year-old loblolly pine plantation in South Carolina, water was removed at a depth of 54 to 66 inches at about the same rate as from shallower depths. More recently, Fletcher and McDermott (3) report that on an Ozark Ridge soil, transpiration depleted soil moisture at a uniform rate until the supply was virtually exhausted.

Differences of opinion as to the effect that amount of soil moisture has on rate of transpiration probably arise in part from the fact that different investigators have used different plant materials, soils, and techniques of measurement. Furthermore, there seems to be no simple or certain method of measuring moisture in deep soil profiles. It is also worth mentioning that a number of investigators have considerable misgivings about some of the

transpiration rates found in literature. Stone (19), for example, states "...evaporation measured from isolated trees or portions thereof cannot be related, even theoretically, to losses from an area of forest vegetation nor can the results of conventional pot cultures."

Considering that no attempt is made to differentiate between soil types in this report, and that only an approximation of soil moisture is intended, it will be assumed in this paper that rate of moisture depletion is the same from field capacity to wilting range.

SOIL MOISTURE MEASUREMENT

Irrigationists, soil technicians, hydrologists, engineers, foresters, and many others are concerned with daily and periodic changes in soil moisture. Consequently, much attention has been given to devising measurement techniques. Brief mention of the methods most commonly used will be made here, mainly for the purpose of emphasizing that there is no easy, accurate, and inexpensive way of measuring soil moisture. This is particularly true of forest soils, where depth of profile is measured in feet rather than inches.

The simplest yet the most laborious and time-consuming method of measuring soil moisture is to weigh the fresh field sample, ovendry it to constant weight, reweigh it, and express the moisture content in percent of ovendry weight. If bulk density--the relation of the weight of the ovendry sample to its field volume--is known, moisture content can readily be converted to volume percent.

The main difficulty in this gravimetric method is in obtaining samples. Although a variety of soil tubes, augers, and mechanized core drillers have been developed, the necessary labor places a physical limitation on the number of samples that can be obtained in a day. This is a decided disadvantage where close watch of daily moisture is desired. Another disadvantage is that the same point cannot be resampled.

Lull and Reinhart (10) point out that for the gravimetric method, sampling conditions are ideal when the soil is just moist enough so that the sampling instrument can be easily inserted and withdrawn and where roots and stones are not a problem. They add that such conditions are rarely encountered.

To overcome difficulties inherent in gravimetric measurements, electrical units that can be left in place at any desired depth of soil have been developed. The units consist of electrodes variously embedded or contained in blocks of absorbent material, the commonest being plaster of paris, fiberglas, and nylon, or combinations of these. Presumably the moisture content of the absorbent material varies with that of the soil. The measured electrical resistance is an index of soil moisture when the blocks are calibrated for a particular soil.

The electrical-resistance method has certain advantages and disadvantages. A metering unit can easily be attached to terminals leading to blocks at different depths, and measurements made as often as desired without the labor of taking soil samples. However, Olson and Hoover (16), Lull and Reinhart (10), and Haise (4), among others, point out that there are many sources of error. For example, gypsum blocks lack durability; soil salinity can greatly modify measurements; compensation must be made for temperature; units must be carefully calibrated; units must be installed most carefully to avoid gross errors; some types of units are sensitive at certain moisture ranges but not at others; and units must be calibrated periodically against gravimetric determinations.

Two other methods have been used with more or less success. Tensiometers measure water in a soil by means of a porous cup filled with water and attached to the end of a tube inserted in the soil. Tension, and corresponding soil moisture, is determined by means of a vacuum gage or a mercury manometer. Such instruments have been used in estimating irrigation needs but apparently are not satisfactory where the full range of soil moisture is to be determined. Studies of methods for estimating soil moisture by measuring the scattering of neutrons with electronic instruments indicate that further improvements in techniques and instrumentation are needed.

As implied in the previous discussion, all methods of measuring soil moisture require expertness of methodology. There is no simple instrumental method that can be suggested for routine field use by fire control men. Furthermore, as stated by Lull and Reinhart (10), any sampling method gives results that are variable because moisture changes from day to day, point to point, and depth to depth. There can be large variations even within a relatively small area because of uneven wetting of the soil profile by rain, because of soil heterogeneity, uneven root distribution, and uneven surface conditions. To sum up, determination of drought conditions for general field use by fire control men must be by estimation rather than by direct measurement, at least for the present.

TYPE OF VEGETATION AND SOIL MOISTURE DEPLETION

There seems to be no doubt that different types of plants have different consumptive uses. Peak rates per day reported in the Yearbook of Agriculture (23) range from 0.25 to 0.50 inch. The question arises whether pine and hardwood stands differ materially in this respect. Theoretically, hardwoods should use less than pines because hardwood foliage has slightly higher reflectivity, but it is doubtful whether the small difference is significant. Some evidence on this point is available from work at the Southern Forest Experiment Station.

Moyle and Zahner (14) from studies of all-aged pine stands and hardwood stands at Crossett, Arkansas, concluded that soil depletion curves for a depth to 48 inches during a dry period in 1953 were almost identical. This was corroborated by Zahner (27), who reported in another study that the rates of soil

water depletion were approximately the same for pure pine and pure hardwood stands similar in climate, stocking, and site. Although the hardwood curve lagged about a week behind the pine, Zahner attributed this lag to greater water storage under the hardwood stand. He concluded that his results supported theories that evapotranspiration within a given climatic area is independent of the type of forest cover.

That the amount of vegetation on an area greatly influences the rate of transpiration is well known. For example, in one study of a hardwood stand at the Coweeta Hydrologic Laboratory, near Franklin, North Carolina, all the woody vegetation on a watershed was cut, with a resultant increase in streamflow amounting to 17 area inches the first year after cutting, and presumably a comparable reduction in transpiration. Moyle and Zahner (14) found that during hot dry weather in the summer of 1953 pine and hardwood stands with a stocking of 70 to 100 square feet of basal area on the Crossett Experimental Forest quickly depleted soil moisture. On plots where large cull hardwoods had been girdled or all living vegetation removed, soil moisture remained relatively high.

The method of calculating water losses through evapotranspiration suggested in this report is considered as applicable only to fairly well-stocked stands, regardless of type.

ROOT DISTRIBUTION AND SOIL MOISTURE DEPLETION

As has been pointed out, most of the water lost from soil under forest stands is by transpiration. It follows that the distribution of the root system, and particularly the depth from which it can draw water, to a large extent determines how much and how fast water is lost from soil.

Little information is available on the deep root systems of trees. This is understandable considering the difficulty involved in excavating and mapping even the roots of small trees. Furthermore, generalizations are unsafe because root development can be greatly modified by soil structure, amount of water and nutrients present, aeration, competition from roots, and many other factors. Nevertheless, the following citations provide evidence on the depth of pine root penetration.

Heyward (5) reports that a 250-year-old longleaf pine growing on deep sands in western Florida had a taproot extending downward more than 14 feet. Seedlings 10 to 30 inches tall had taproots from 3 to 9 feet long. Ashe (1) illustrates a loblolly pine stump in a moist but well-drained sandy loam with a taproot of 10 feet. He adds that taproots of this species seldom descend to depths of more than 4 or 5 feet. They are much shorter on compact clay soils and hardpan than on loose soils. McQuilkin (12) from a study of pitch pine and shortleaf pine on well-drained sandy soils in New Jersey, states that vertical roots after reaching depths of 3 to 4 feet grew much more slowly than lateral roots and practically ceased to grow at depths of 8 to 9 feet.

Investigators are in general agreement that most of a tree's feeding roots are found in the upper soil layers. Hoover and others (6) state that for this reason there has been a tendency to discount the amount of water withdrawn by roots from deeper depths. They believe, "...root concentration or abundance may not necessarily be a reliable guide to either the rate or amount of water removed from a given soil depth." They also observe that there is abundant root growth in the upper soil layers because conditions there are favorable and not because a large mass of roots is needed to extract water.

In addition to storage capacity by a soil of specific texture, the total depth of profile into which roots can penetrate determines the amount of water available to plants. Rock strata, hardpans, and other impediments to root penetration obviously limit root development.

Perhaps some misconceptions regarding the availability of soil moisture to plant roots are worth mentioning. One might suppose that the water table could contribute considerable moisture to a dry soil. However, according to Lutz and Chandler (11) and others, capillary movement from moist to dry soils is too slow to be of much use to plants. Apparently roots grow pretty much at random but branch profusely when they reach moist and well-aerated areas. Kramer (8) states that there is no evidence that roots actually grow from dry to moist soils.

THE RANGE OF AVAILABLE WATER

The amount of water available to plants differs according to the type of soil and depth of profile. By available water is meant the amount between field capacity and wilting point. Field capacity is usually considered to be the amount of water that is held against gravity in a given depth of soil after saturation. Water in excess of this amount is called gravitational water and usually drains off in a few days or hours depending on type of soil. Wilting point has been defined in several ways: (a) the moisture content of soil when leaves of plants become permanently wilted; (b) the lower limit of soil moisture available for growth but not the lower limit available for absorption; and (c) the moisture held by soil against a force of 15 atmospheres.

The range of so-called constants for soils of different textures is given in figure 1. It will be noted that clay soils can hold much more water per foot than sandy soils, but they also have a higher wilting point.

The Southern Forest Experiment Station at the Waterways Experiment Station at Vicksburg studied the water-holding capacity of 37 soils. Field capacities ranged from 32 percent by volume for sandy loams to 42 percent for the heaviest soils. Wilting points by volume were 10 percent for sandy and silt loams, 14 percent for loams, and 25 percent for clays. Available water for silt loams averaged 30 percent, loams 25 percent, sandy loams 22 percent, and clays 17 percent.

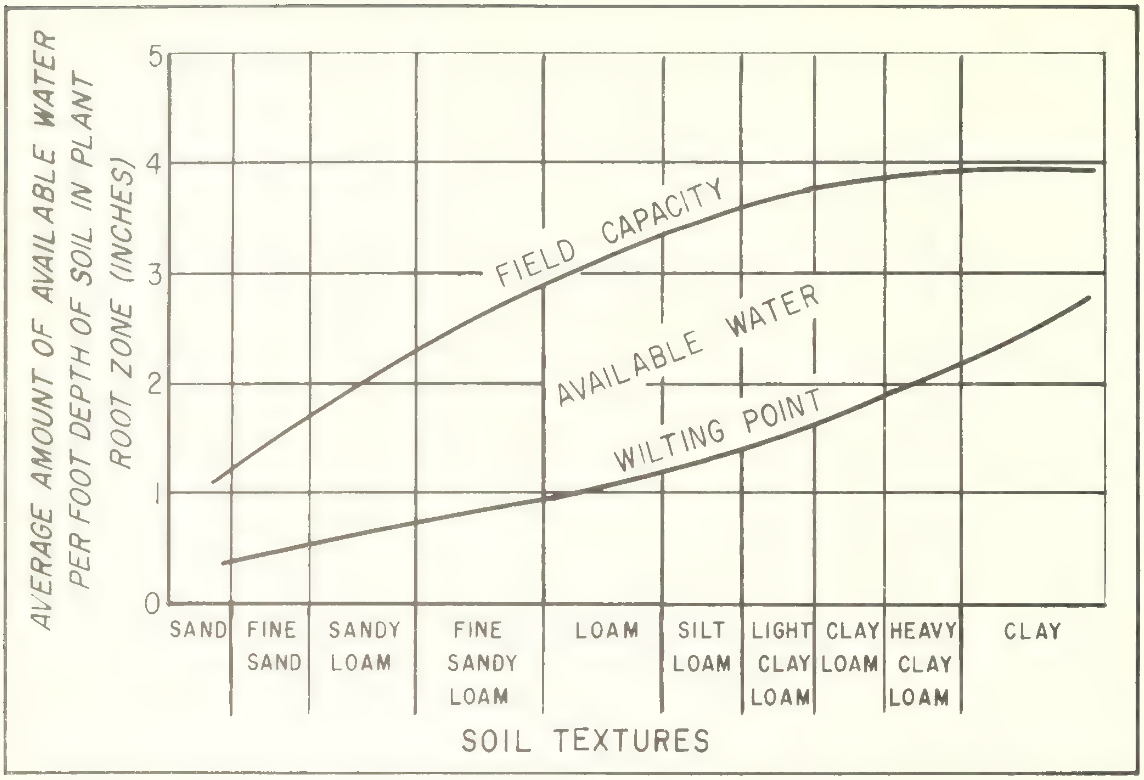

Figure 1.--Typical water holding characteristics of different-textured soils. (Adapted from 1955 U. S. Department of Agriculture Yearbook.)

According to Kramer (8) and many other investigators, plants can absorb water from soils drier than the wilting point, but absorption is too slow for diameter growth. Also, there is apparently little root growth in soils at or near the permanent wilting percent.

Reynolds (17) considers that forest soils in northern Louisiana and southern Arkansas can store from 8 to 14 inches of available water. This, he believes, is enough to allow for maximum growth of a well-stocked stand for 2 to 4 weeks without rainfall and for 4 to 7 weeks at some growth.

For purposes of illustration in later sections of this report, a 6-foot forest soil depth with a water-holding capacity of 2 inches per foot has been selected.

SOIL MOISTURE ACCRETION

The amount of water that actually enters the ground during or after a rain depends on many factors. Among these are amount, duration, and intensity of rainfall, amount of water present in the soil, type of soil, infiltration capacity, kind and depth of protective mantle, slope, and ground cover. Even if the individual or collective effects of these variables on accretion were known, it would not be possible to include them in any simple system of estimating soil moisture such as is proposed.

Much has been written about interception of precipitation by tree crowns and other forms of vegetation. Hoover and others (6) report that, on the average, in the pine plantation under observation, rainfall reaching the ground was 86 percent of that in the open. A large proportion of light rains but only a remarkably small percent of water by heavy rains was held by interception. They suggest that for pine stands the importance of interception may have been overemphasized. Thornthwaite and Hare (22), and Russell (18) (cited by Lull) state that energy used in evaporating intercepted water cannot be used in transpiration and therefore there may be no actual loss. In view of this concept, and in the interest of simplicity, interception as a factor in calculating accretion is ignored.

As was pointed out earlier, capillary water apparently does not move rapidly either upward, downward, or sideways. Kramer (8) states that if the water table is only a few feet below the surface, little upward movement occurs. This no doubt explains in part why some deep-burning ground fires in coastal organic soils during drought periods are not completely extinguished except by a drenching rain or a rise in the water table sufficient to drown the fire.

If a flat soil is at or near field capacity, most or all precipitation must seek lower levels such as ponds, bays, or streams. Similarly, if precipitation is of a duration and intensity that is beyond the infiltration capacity of the soil, the excess runs off. Since this report is primarily concerned with the flatwoods, runoff as a factor in accretion has been ignored except as follows: If, for example, a hypothetical soil profile with a field capacity of 12 inches has a computed 11 inches of water, the amount of rain in excess of one inch is considered as gravitational water and does not enter into accretion calculations.

After assuming that all precipitation up to field capacity could be considered as a deposit to the soil moisture bank, the next step was to derive transpiration loss values. Before proceeding with a discussion of how this was done, it may be well to summarize some of the other major assumptions made so far in this paper.

1. Mean daily temperature is the simplest determinant of rate of evapotranspiration. In this report mean temperature is an average of the highest and lowest temperatures for the day.

2. The rate of moisture depletion is the same from field capacity to wilting range.

3. A 6-foot soil profile with a field capacity of 2 inches per foot is representative of many forest stands in the South.

4. Interception and runoff need not enter into the calcuation of available water.

DERIVATION OF EVAPOTRANSPIRATION VALUES

Because mean temperature is recognized generally as the principal determinant of evapotranspiration, it was necessary to arrive at a set of water-loss values for a range of mean temperatures. These will be referred to as ET's. Search for such values that could be applied to forest stands led to work of the Southern Forest Experiment Station at the Waterways Experiment Station, Vicksburg, Mississippi. One of its reports (24) contains a curve of potential evapotranspiration based on Thornthwaite's formula (21) and average season transition dates. The curve of evapotranspiration values and a superimposed curve of Vicksburg mean temperature normals (1921-1950) is reproduced in figure 2. From these curves, preliminary ET's were derived that were about 25 percent less than the final values in table 1.

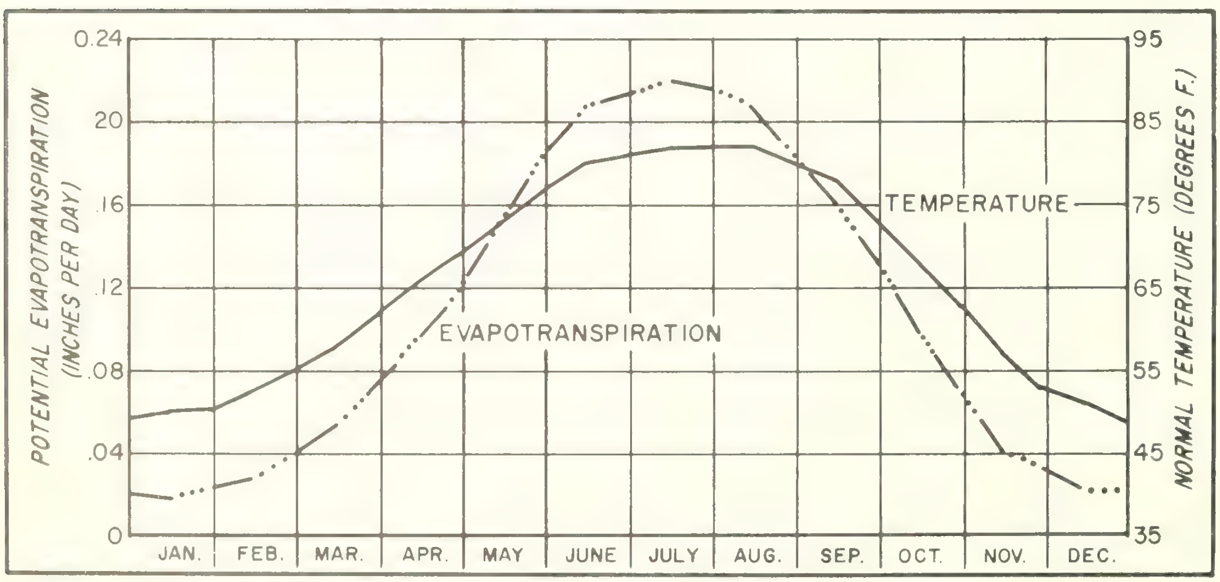

Figure 2.--Potential evapotranspiration values and normal temperatures for Vicksburg, Mississippi.

Table 1.--Estimated soil moisture loss according to daily mean temperature

Daily mean temp.	ET loss	Daily mean temp.	ET loss
Degrees F.	Inches	Degrees F.	Inches
50	.02	68	.13
51	.03	69	.14
52	.04	70	.14
53	.04	71	.15
54	.04	72	.16
55	.05	73	.17
56	.05	74	.18
57	.05	75	.19
58	.06	76	.20
59	.06	77	.21
60	.07	78	.23
61	.08	79	.24
62	.09	80	.25
63	.09	81	.26
64	.10	82	.27
65	.10	83	.28
66	.11	84	.30
67	.12	85	.32

Next, an approximation was attempted of the moisture depletion curve for the Crossett, Arkansas, untreated hardwood stand reported by Moyle and Zahner (14). Mean temperatures and rainfall for the period May 21 to July 14, 1953, were obtained from a report by Moyle (13) supplied by the Southern Forest Experiment Station. This period was selected because the soil was at field capacity at the beginning of the period and was later wetted by only small rains amounting to 1.12 inches. Using the preliminary ET's, subtractions from the soil moisture beginning on May 21 were made successively each day according to the mean temperature for that day. On days with rain the full amount of precipitation was counted as an accretion to the soil moisture. The measured depletion of available water in the hardwood site scaled from the curve in Moyle and Zahner's report (14), and my estimated depletion according to the just-mentioned procedure are given in figure 3. As will be seen, the rate of estimated depletion approximated the actual rate fairly well.

When a similar comparison was made using the all-aged Crossett pine stand depletion curve from Moyle and Zahner's report (14), and daily mean temperatures and precipitation reported for that site, a much poorer approximation was obtained (fig. 4). Because pine areas were of primary interest, a better set of ET values was sought by arbitrarily raising the preliminary values 25 percent (table 1).

These new ET's were used to estimate depletion for both the Crossett hardwood and pine sites (figures 5 and 6), with somewhat more satisfactory results, at least for the pine site. The ET's in table 1 were therefore used to derive illustrative depletion curves found later in this report.

It is apparent from the foregoing that the method used in deriving ET's has no very substantial basis, although there is some evidence that at higher mean temperatures the values may be reasonable. Zahner (28) estimated the water needs of forest stands in the mid-South for June, July, and August at about 8 inches per month. To compare my ET values against this figure, average monthly temperatures for 15 widely separated stations in the region were computed. They were found to be 79, 81, and 81 degrees respectively. Assuming a 31-day month, a mean temperature of 81 degrees, and an ET value of 0.26 from table 1, my estimated water loss is 8.1 inches. From another

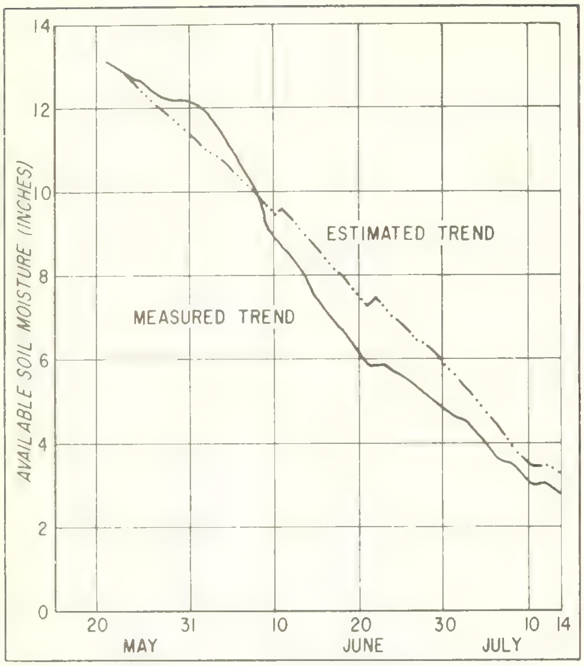

Figure 3.--Trend of available soil moisture in upper 48 inches on untreated hardwood site, Crossett, Arkansas, 1953 (adapted from Moyle and Zahner), and estimated depletion using preliminary ET's.

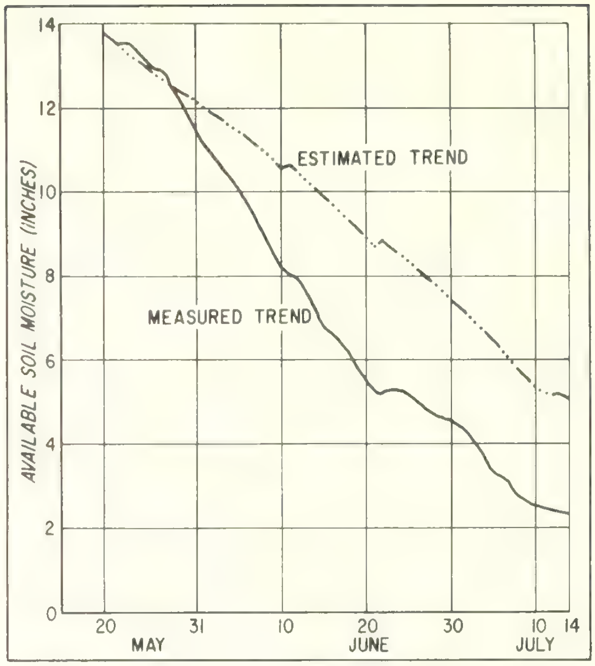

Figure 4.--Trend of available soil moisture in upper 48 inches on pine site, Crossett, Arkansas, 1953 (adapted from Moyle and Zahner), and estimated depletion using preliminary ET's.

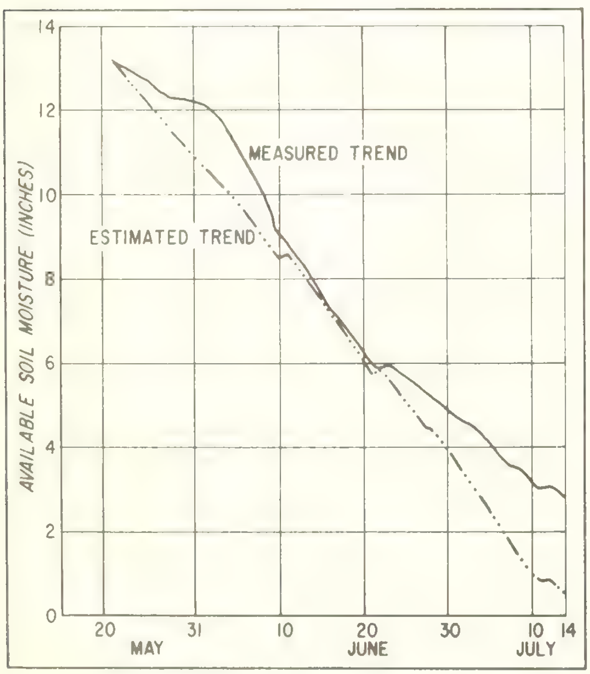

Figure 5.--Trend of available soil moisture in upper 48 inches on untreated hardwood site, Crossett, Arkansas, 1953 (adapted from Moyle and Zahner), and estimated depletion using ET values from table 1.

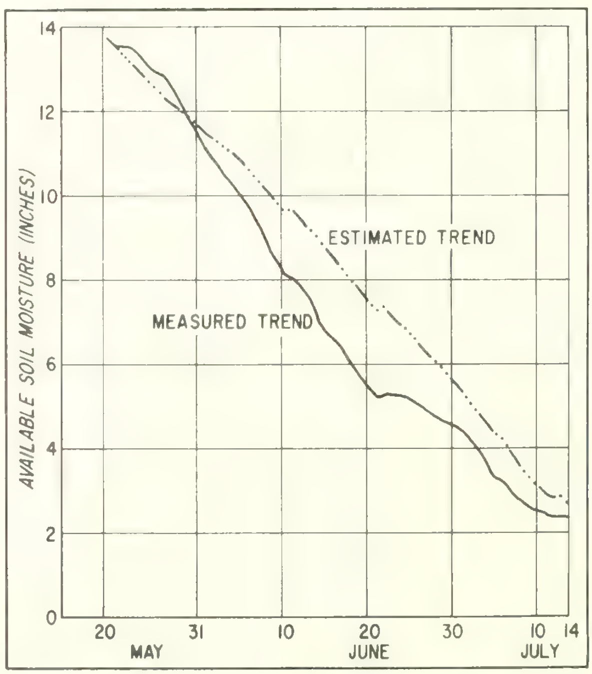

Figure 6.--Trend of available soil moisture in upper 48 inches on pine site, Crossett, Arkansas, 1953 (adapted from Moyle and Zahner), and estimated depletion using ET values from table 1.

study on the Crossett Experimental Forest, Zahner (27) estimated that for a 6-week period following June 2, 1954, the average soil moisture loss per day was about 0.25 inch in a 60-inch profile in both pine and hardwood stands. Using daily mean temperatures from Crossett Weather Bureau records for the same 6-week period and ET's from table 1, the writer calculated an estimated loss of 0.265 per day.

EXAMPLES OF ESTIMATED SOIL MOISTURE DEPLETION CURVES

During the course of the study reported in this paper a number of depletion curves were computed for Macon, Georgia, and District 2 in north Florida. Some of the curves are presented to illustrate the estimated march of soil moisture in drought and nondrought years.

Macon, Georgia, 1953-1954

Daily soil moisture values were computed for the Macon, Georgia, area beginning in April 1952. This month and year were selected as the starting point because the previous February and March had a total precipitation of 7.30 and 7.96 inches respectively. Field capacity for an assumed 6-foot profile almost certainly was reached during that period. Only values for 1953 and 1954 are plotted (fig. 7).

In examining these curves, the reader should remember that low moisture values in any particular month do not necessarily mean that a drought condition exists. For example, if soil moisture in the spring is at a low point, well scattered rains amounting to 8 or 9 inches in each of the summer months should supply ample moisture to upper soil layers for tree growth even though the soil profile as a whole may be relatively dry. It is the sharp decline in the curve, such as occurred in late May and part of June in 1953, and particularly the last half of May and all of June in 1954, that indicates the beginning of severe conditions. If such conditions are followed by weeks of low rainfall, then the drought becomes progressively worse.

The incipient drought in May and June of 1953 was followed by above-normal precipitation in July. This not only counterbalanced the heavy evapotranspiration draft but added somewhat to the water balance. Precipitation much above normal in late September, having again raised the level of soil moisture, partly offset the very low rainfall in October and November. For those months Macon Weather Bureau officials reported dry conditions, but apparently there was no critical shortage of soil moisture.

According to Weather Bureau data, rainfall in 1953 was nearly 12 inches above normal. This excess coupled with cooler than average temperatures brought about relatively moist conditions, as is suggested by the estimated depletion curve for that year.

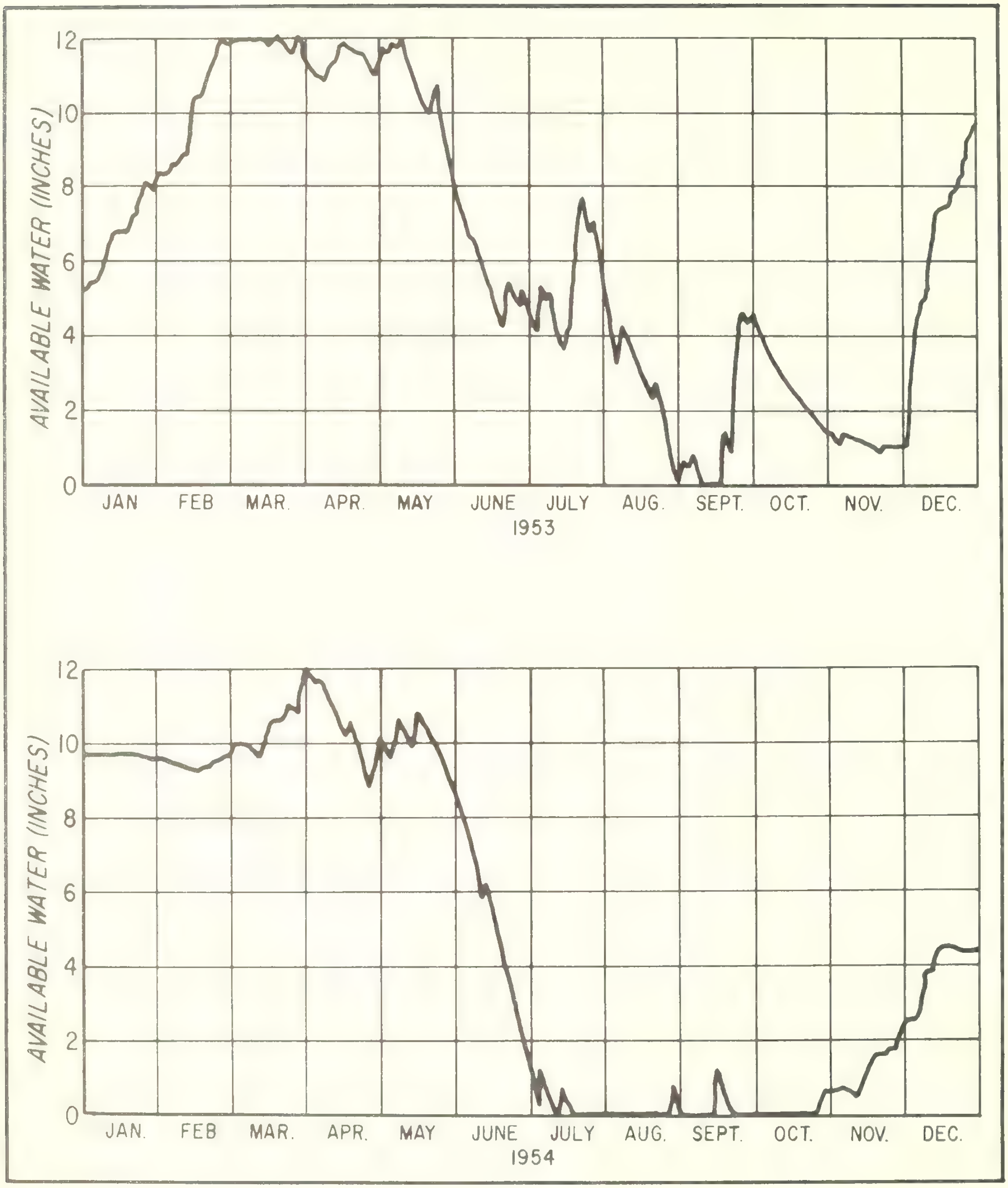

Figure 7.--Estimated soil moisture depletion, area of Macon, Georgia, 1953-1954.

The depletion curve for the last 6 months of 1954 presents a different picture. From all accounts it was one of the driest years on record. Total precipitation was only 56 percent of normal, and there was a deficiency in every month but November. Even so, during January, February, and March--which are months of low evapotranspiration--soil moisture remained high. It also remained high through April and the first half of May. After that, above-normal temperature and below-normal precipitation rapidly reduced soil moisture. During most of July, August, September, and October, soil to an assumed depth of 6 feet must have been at or near the wilting point.

The summer drought in mid-Georgia caused much damage to both crops and forests. Macon Weather Bureau officials reported that in June all growing crops had been damaged, in July the drought had reached major proportions, and in September practically all crops had been damaged beyond recovery, and that water sources were drying up. Brender and Hodges (2) estimated that the average loss of merchantable-size pines from mortality resulting from the 1954 drought in mid-Georgia was equivalent to one-half the normal growth in basal area, and that diameter growth of survivors was reduced by one-half. Death of seedlings and saplings caused additional losses.

Pine stands apparently are able to endure a surprising amount of dry weather. Hoover and others (6) found that during the severe drought in 1951 in the vicinity of Union, S. C., soil to a depth of 66 inches was at its wilting point for most of August. Though tube samples indicated no available water in the upper 96 inches of soil, no signs of wilting or unusual needle drop was observed.

Summer droughts in the South probably occur more frequently than is generally recognized. Moyle and Zahner (14) state, "During the summer, droughts occur nearly every year throughout the western portion of the shortleaf-loblolly pine-hardwood type, and lack of moisture undoubtedly limits tree growth." The same is probably true of a large part of the South.

District 2, Florida, 1953-1957

Depletion curves were computed for District 2 in north Florida for a period that included several extremely severe drought years. The District is a fire protection unit of the Florida Forest Service comprising 10 counties and bounded on the west by the Appalachicola River and on the east by the Suwanee River. Daily precipitation figures were obtained by averaging U. S. Weather Bureau records from 10 stations well scattered in the District. Mean temperatures for Tallahassee only were used, on the assumption that the city's central location provided reasonably good average figures for the area. Daily soil moistures were calculated, but for convenience semimonthly values only are plotted in figure 8.

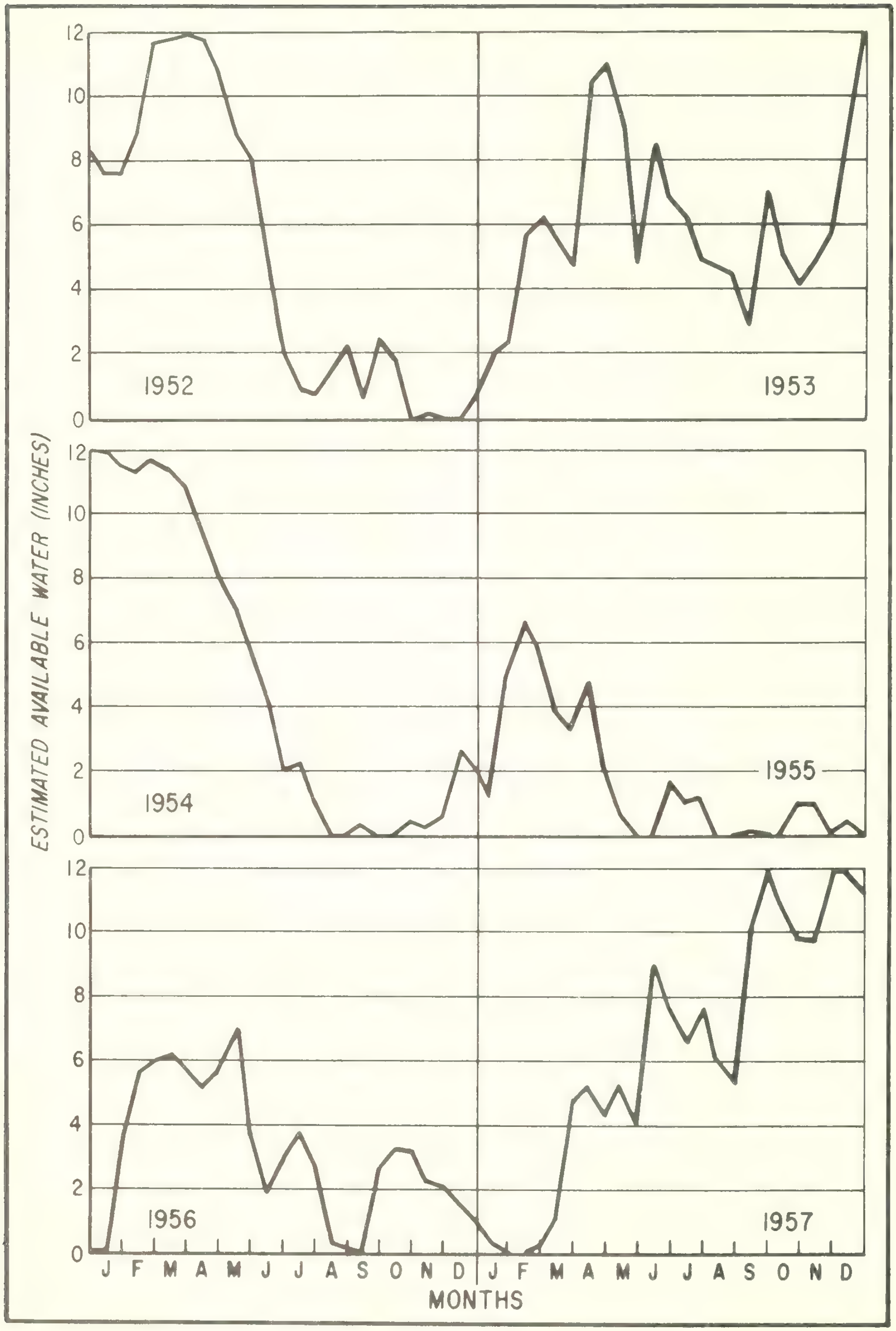

Figure 8.--Estimated soil moisture depletion curves, District 2, north Florida.

The main purpose of this series of soil moisture estimations was to determine whether definite relations between moisture depletion and fire history in the area for different years could be established. Accordingly, monthly records on number of fires, acres burned, and total acres protected were obtained from the Florida Forest Service. Analysis showed no clear-cut relation between number of fires and acres burned per million acres protected. Neither was average size of fire well related to trends in the depletion curves. This lack of relation was not entirely unexpected because certainly a great many factors other than soil moisture influence fire occurrence and behavior. For example, frequent light rains during a fire season may add little to the soil-moisture bank but may wet fuels enough so that fires do not easily start or spread. Acres burned and average size of fire as related to soil-moisture conditions can also be misleading because a single conflagration may exceed the total acreage burned in a protection unit even in a severe year.

Number of fires and acres burned per million acres protected in 1957 were decidedly lower than for any other year in the period. The next lowest year was 1953. The largest number of fires occurred in 1954, but 1955 was far in advance of other years in acres burned. These comparisons may not have much significance, since they do not take into account such factors as total Burning Index, adverse atmospheric conditions, manpower or machine efficiency, effectiveness of prevention, or increased funds available for fire protection.

According to observers, 1954 and 1955 were extremely difficult from a fire suppression standpoint in District 2 because of severe drought conditions. One State fire control official stated that from about August 1954 to the middle of June 1955, dry conditions made fire control almost impossible, particularly in swamps where muck and peat burned fiercely. A National Forest official reported that fires were very difficult to control in 1954, but in 1955 the situation became critical because of lack of soil moisture. There was some relief in 1956, but ponds and bays still remained relatively dry. Depletion curves for 1954, 1955, and 1956 appear to be in keeping with the foregoing reports.

APPLICATION

Following are suggestions to fire control men who think that some numerical measure of soil moisture conditions would be helpful and who are interested in testing the preliminary method described in this report:

1. Select one or more forest stations from which reliable daily precipitation and maximum and minimum temperature records are available.

2. From test borings, soil pits, or other sources of information in the general area of the station, estimate the depth of soil profile into which tree roots are able to penetrate.

3. Assume available water to be 2 inches per foot of profile depth, except for very sandy soils and unless specific information on this point can be obtained.

4. Select a starting date in the winter or spring when soil is at field capacity; that is, when there has been enough precipitation to wet the root zone thoroughly. An indicator of this condition is standing water for a few hours or days. Depth of saturation can be checked by test borings.

5. From the assumed number of inches of available water, make daily subtractions of estimated evapotranspiration according to mean temperatures and the ET values in table 1; on days with rain add the amount of precipitation minus the ET value for the day to the water balance but not to exceed the original inches of water. A sample form and graph are given in figures 9 and 10.

6. During periods of low rainfall, observe trends in the depletion curve and note at what points fire suppression becomes progressively more difficult because of a lowering of soil moisture.

7. From a series of such observations develop supplemental guidelines for fire control action during drought periods.

SOIL MOISTURE DAILY RECORD

Station ________________ Month ________ Year 19 __ Observer ________________

Day	Maximum Temperature	Minimum Temperature	Max. + Min. Temperature	Mean Temperature	ET	Rain	Estimated Soil Moisture	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
	---Degrees Fahrenheit---				Hundredths inches		Inches	
1	--	--	--	--	--	--	12.00	
2	82	58	140	70	14	--	11.86	
3	89	53	142	71	15	--	11.71	
4	85	63	148	74	18	--	11.53	
5	81	60	141	71	15	222	12.00	
6	73	47	120	60	7	--	11.93	
7	79	45	124	62	9	--	11.84	
8	81	48	129	65	10	2	11.76	
9	67	40	107	54	4	--	11.72	
10	71	41	112	56	5	--	11.67	
11	70	45	115	58	6	8	11.69	
12	77	55	132	66	11	--	11.58	
13	65	50	115	58	6	--	11.52	
14	67	43	110	55	5	--	11.47	
15	70	36	106	53	4	--	11.43	
16	76	46	122	61	8	--	11.35	
17	78	58	136	68	13	--	11.22	
18	79	63	142	71	15	2	11.09	
19	86	61	147	74	18	--	10.91	
20	86	62	148	74	18	--	10.73	
21	89	63	152	76	20	--	10.53	
22	88	66	154	77	21	3	10.35	
23	87	63	150	75	19	--	10.16	
24	86	60	146	73	17	--	9.99	
25	89	60	149	75	19	--	9.80	
26	87	60	147	74	18	--	9.62	
27	89	63	152	76	20	--	9.42	
28	88	60	148	74	18	--	9.24	
29	89	62	151	76	20	--	9.04	
30	87	63	150	75	19	--	8.85	

Figure 9.--Numbers in column 5 are numbers in column 4 divided by 2. ET and rain are recorded in hundredths inches to avoid possible errors resulting from misplaced decimal points. ET values are obtained from table 1. Twelve inches of soil moisture were assumed to be available on the first day of the sample month.

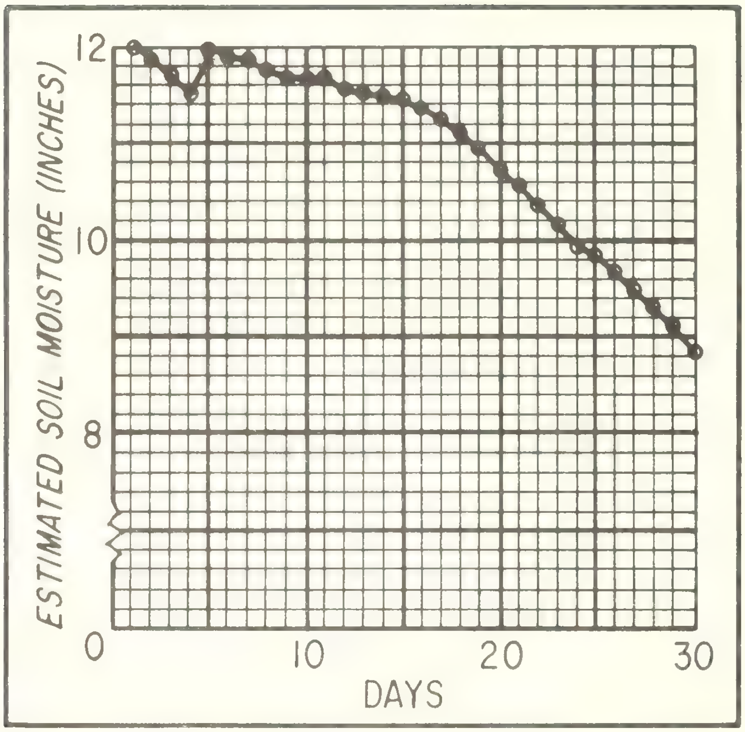

Figure 10.--Graph of estimated soil moisture, from column 8, figure 9.

Certainly much more work is needed to develop methods for estimating soil moisture depletion in forest stands and to determine what different degrees of depletion mean in terms of fire control. Such work is planned by the Southeastern Forest Experiment Station. In the meantime the writer will welcome letters or communications giving results of field trials; also opinions on the success or inadequacy of this tentative method.

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Station Paper No. 100

April 1959

Forest Insect Conditions in the Southeast During 1958

by

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FOREST INSECT CONDITIONS IN THE SOUTHEAST DURING 1958

by

W. P. Nagel

INTRODUCTION

Losses, in terms of killed trees, in the Southeast during 1958 were less than they had been in many years. This was mainly due to the absence of any sizeable bark beetle outbreak, quite a rarity, in any part of the Southeastern region. However, other forest insect outbreaks have caused considerable warranted concern. Figure 1 shows the locations of the various major insect outbreaks that took place during the year.

In brief, low temperatures in the southern Appalachian Mountains the winter of 1957-58 halted the southern pine beetle epidemic. Black turpentine beetle activity diminished by the middle of the year. Two pine sawfly epidemics, one in Virginia and North Carolina and the other in north-central Florida, occurred on about 400,000 and 300,000 acres, respectively. An expanding outbreak of the balsam woolly aphid, a notorious killer of true firs, was discovered on Mt. Mitchell, North Carolina, and adjacent lands. The hardwood defoliator, elm spanworm, in Georgia, Tennessee, and North Carolina spread over 570,000 acres of forest in the southern Appalachians.

The information contained in this report is not that solely obtained by Federal entomologists. Much of the data was furnished by the various state and private organizations in the Southeast. The detection and reporting programs in the area are gradually being increased and perfected as the impact of losses due to forest insects is being realized. In addition to improving these reporting systems, key personnel in the states work mainly on forest pest problems. During 1958, the State of South Carolina employed an entomologist to work mainly on a detection system, and Virginia added another technical man to its insect and disease section. The strengthening of these positions is an indication of the importance foresters attach to insects in the South.

SOUTHERN PINE BEETLE

The epidemic of the southern pine beetle that had existed in the southern Appalachian Mountains since 1952-53 came to an end in 1958. An outbreak of moderate size took place on some private lands in the tidewater section of eastern North Carolina.

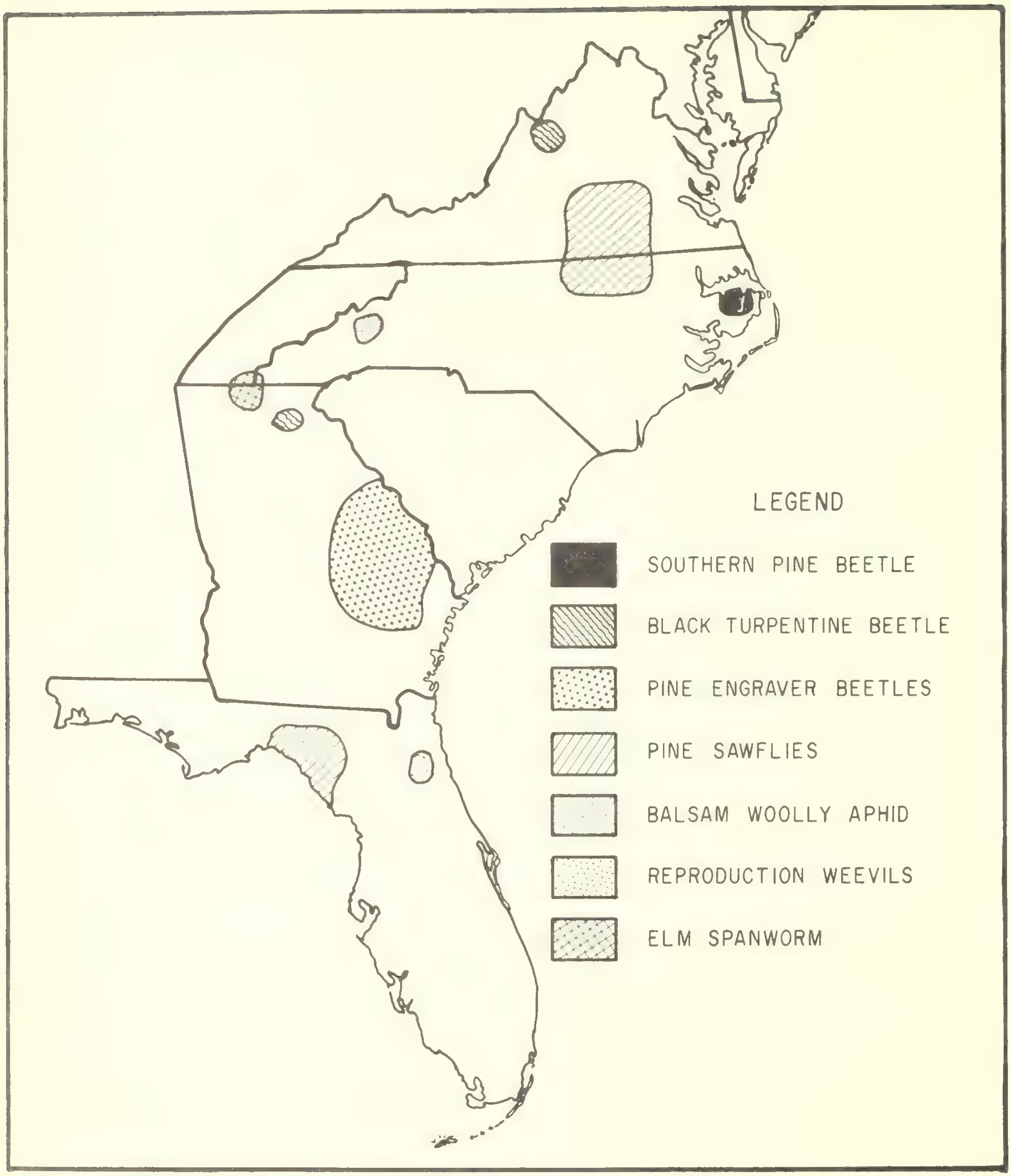

Figure 1.--Major forest insect outbreaks in the Southeast in 1958.

During the 1957-58 winter in the mountain areas of North Carolina, Tennessee, Georgia, and South Carolina the lowest temperatures in many years were recorded on several occasions. Appraisals to determine the effectiveness of these temperatures on the overwintering stages of the beetle were conducted in April. These examinations revealed that, exclusive of eggs, from 95 to 100 percent of the broods had been killed. This high mortality prompted the advice to the various control units that the spraying of infested trees be stopped.

Operational aerial surveys were conducted by the control units throughout the spring, summer, and fall until hardwood coloration prevented accurate mapping. On a few of these flights red-topped pines were observed, but subsequent ground checks showed that in most instances these trees had been killed by either Ips or black turpentine beetles. Because of these continued negative results, all control activities were halted by the end of the year.

Activity of the southern pine beetle on private lands in Tyrrell County, North Carolina, was reported during June. An aerial survey of the area revealed that 36 spots containing about 450 trees were located in a 145-square-mile area. Ground examinations showed that beetle populations in the infested trees were large and vigorous, and it was predicted that a possible 3 to 1 increase in the number of attacked trees could occur with the succeeding generation. Even though a population buildup was expected, the nature of the terrain was such that chemical control was not practical or practicable. This section of North Carolina is subject to frequent flooding, and the dense undergrowth would have made treating costs prohibitive in most locations. Salvage of the dying timber and removal of many of the overmature loblolly and pond pine was employed as a control measure.

In the second aerial survey of the area, in September, results showed that the rate of increased infestation had not been as great as anticipated. It was estimated that about 800 trees were infested, or slightly less than a two-fold increase over that observed in June.

The third aerial survey and subsequent ground examinations were conducted in December. Seventeen infested areas of about 200 fading pines were detected, with the greater concentration still in Tyrrell County. One new spot was observed in adjacent Hyde County, and another was seen in central Dare County. A biological evaluation of a few of the affected spots showed that population vigor of the beetle had been greatly reduced. In addition to the fewer and smaller broods per attacked tree, the number of infested trees per spot was also less. The epidemic appears to have definitely subsided, and it will probably end during 1959 if the present trend continues.

PINE ENGRAVER BEETLES

Other than what may be considered as normal, losses by the pine engraver beetles, Ips spp., took place only in isolated, weakened, and attractive trees; few concentrations of attack were noted. During October and November, however, in eastern and southeastern Georgia Ips activity was reported. Infested spots up to one-half acre in size were observed; large-scale attacks did not follow. Drought conditions prevailed during the latter summer months and into the fall and might possibly have precipitated these outbreaks.

BLACK TURPENTINE BEETLE

During the first months of the year and into early spring, turpentine beetle activity was rather prevalent throughout the Southeast. Infestations on the Hofmann Forest in eastern North Carolina remained at a high level, and numerous reports were received from the mountain areas.

Attacks by the black turpentine beetle had been associated with cutting on the private lands of the Hofmann Forest for several years, each time killing many trees in the residual stand. During a survey in March, many of the residual trees in cutover areas continued to be attacked by the beetle, and it was expected that these near-epidemic conditions would continue throughout the year. A second survey in June, however, showed that turpentine beetle attacks had greatly decreased. No further reports were received concerning increased activity.

Chemical control against the turpentine beetle took place in a 50-year-old white pine plantation of the George Washington National Forest. Some attacks requiring control had occurred in 1957 in this same area; while most infestations in 1958 were in stumps and trees injured during thinning operations, control measures were applied because of the potential hazard existing and the values involved. Examinations of this stand in June and July revealed that tree mortality had been negligible and that very few active populations remained.

Examinations of the turpentine beetle control projects on the Chattahoochee National Forest in northern Georgia were made in June. Chemical spraying of stumps and infested injured trees had taken place during early spring. The June check showed that relatively few attacks were occurring on uninjured standing trees and that stump populations were not heavy. Continued treatment in logged areas was not advised unless attacks became heavy in the residual trees.

Since early summer no reports have been received of black turpentine beetle attacks in any state in the Southeast.

BALSAM WOOLLY APHID

During the fall of 1957 a fir aphid identified as the balsam woolly aphid, Chermes piceae, was found infesting Fraser firs on Mt. Mitchell, North Carolina. In the spring of 1958, thousands of dying firs were noted on about 1,500 acres of private and national forest lands. The first entomological appraisal indicated that the aphids were the sole cause of this mortality. However, since some of the typical symptoms associated with this insect were lacking, it was thought that possibly other factors were involved. Subsequent examinations by other entomologists substantiated the belief that the aphid was the primary cause of the Fraser fir mortality.

This aphid, which was introduced into the United States from Europe and first reported in 1908, is a notorious killer of true firs and has been a serious pest in northeastern Canada and United States and in the Pacific Northwest for several years. In these areas it is primarily important as a killer of commercial-value trees, whereas in the Southeast, where acreage of fir is only about 25,000 acres, it offers a threat to scenic and recreation areas and to an expanding Christmas tree industry. A fir aphid was discovered on the Shenandoah National Park, Virginia, in 1956, and was first identified as Chermes nusslini, a species similar in habits and taxonomy to the balsam woolly aphid. However, recent identifications have shown that C. piceae is the insect involved in Virginia also.

Since natural stands of fir, usually associated with red spruce in the Southeast, are isolated and most often above 5,000 feet elevation, and since the aphid is not easily dispersed by its own means, the infestations in North Carolina and Virginia have undoubtedly been artificially initiated. The initial aphid populations were most likely introduced on planting stock of fir from some other infested area in the United States some years ago.

Surveys to determine the extent of the aphid infestations in the vicinity of Mt. Mitchell were conducted. From these surveys and with the aid of aerial photographs taken by men of the Beltsville Forest Insect Laboratory, a spruce-fir type map was constructed and areas on which distinguishable mortality had occurred were delineated. Figure 2 and table 1 show the results of these surveys.

It has been estimated that about 20 to 25 percent of the fir within the areas suffering mortality have been killed and 90 percent of the remaining trees have bole infestations. However, ground checks revealed that the aphid is spread throughout the 7,000 acres of spruce-fir type, even though mortality has not occurred in all areas. Presently it is impossible to estimate with any accuracy the number of infested firs. Aphids have been observed in all locales except on ridge tops and other aspects where wind conditions are most severe.

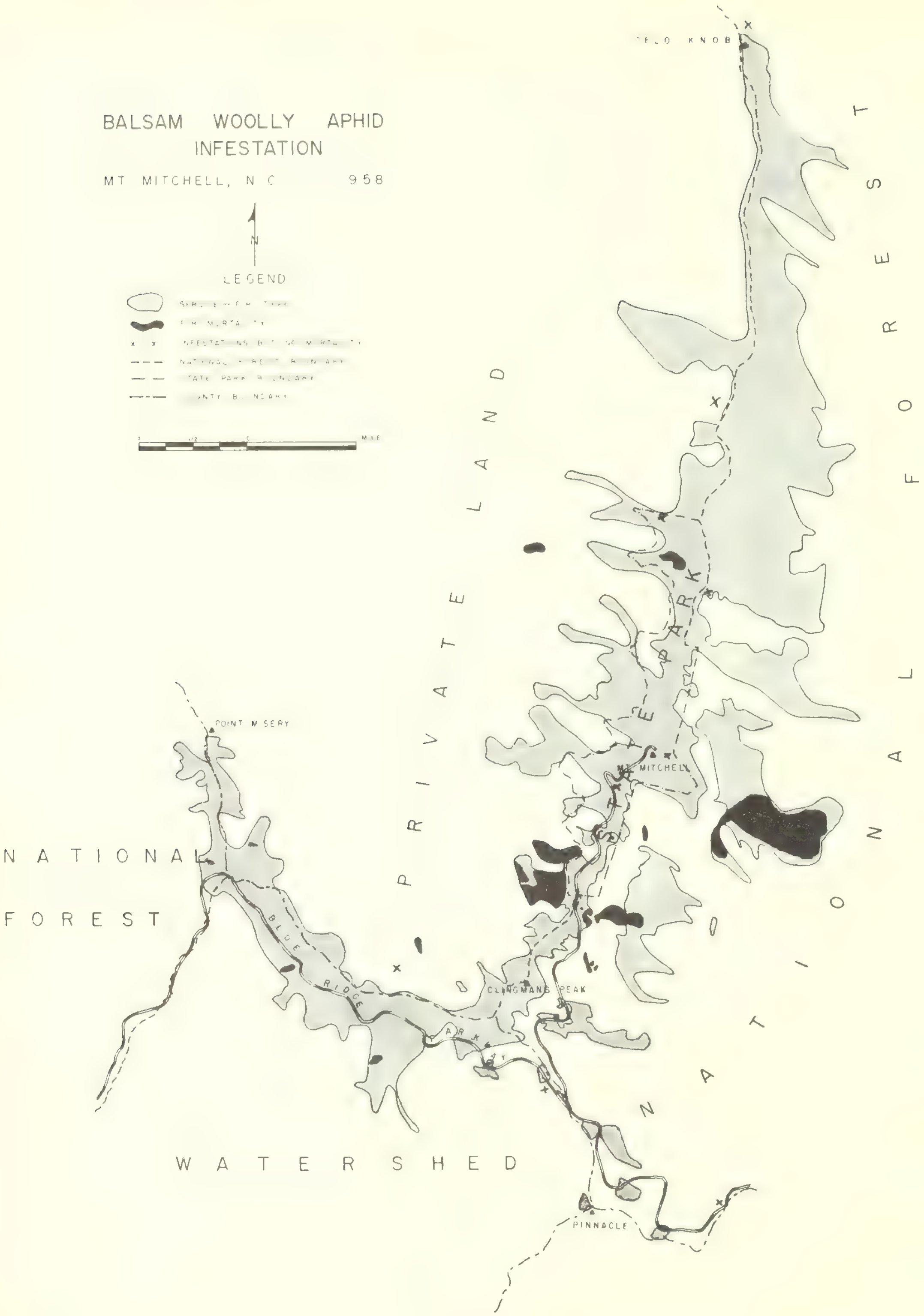

Figure 2.--Balsam fir losses on Mt. Mitchell are causing great concern because the mountain is one of North Carolina's foremost scenic attractions, visited by several hundred thousand people per year.

Table 1.--Balsam woolly aphid infestations on Mt. Mitchell, North Carolina, and adjacent lands, 1958

Type of ownership	Spruce-fir type 1/	Over 20 percent fir mortality	Firs killed
	Acres	Acres	Number
National Forest	3,740	285	5,700
Private lands	1,600	70	5,000
Mt. Mitchell State Park	860	9	180
Asheville watershed	860	5	110
Blue Ridge Parkway	2/ 465	(3/)	(3/)
Total	7,525	369	10,990

1/ Spruce-fir type is forest in which 50 percent or more of the stand is in spruce and/or Fraser fir.
2/ Of this total, 420 acres are also part of the Asheville watershed.
3/ Mortality not extensive enough to be easily measured.

At a special meeting of all concerned landowners, the main decisions reached concerning future action were as follows:

All available information to deal with this situation should be utilized, a pilot test of spraying insecticides to save roadside trees should be established, and research to develop sound methods of control should be conducted. To date several insecticides have been screened for controlling the aphid, plots to examine the effectiveness of cutting as a control measure have been established, and some studies to explore the biology of the insect have started.

Aerial surveys and ground examinations of all other spruce-fir stands in North Carolina and Tennessee have been completed and no infestations of the aphid have been detected. A possible suspect area on Mt. Rogers in Virginia was observed from the air, but as yet a ground check of this area to evaluate the condition has not been made.

PINE SAWFLIES

North Carolina and Virginia.--During early May an epidemic of pine sawflies, later identified as the Virginia pine sawfly, *Neodiprion pratti pratti*, was detected on the Piedmont Plateau of North Carolina and Virginia. It is possible that this is the same species reported in 1957 as being active in localized areas in the southeastern part of Virginia.

To determine the extent of the infestation, aerial surveys were conducted in late May, when larval feeding was completed, and prior to the development of new foliage. Defoliation occurred sporadically; within the scattered stands affected, some were free of feeding. Virginia and shortleaf pines were the only species on which feeding took place. North Carolina forests affected totaled about 50, 000 gross acres, of which 13, 000 acres were actually defoliated. The epidemic extended through 333,000 acres in Virginia, with some 117,000 acres of pine forests defoliated. The infestation area encompassed 48 counties in the two states.

Since only one generation of these sawflies occurred, and as its feeding was completed prior to 1958 foliage development, no mortality was noted. The possibility that the trees might have been weakened and become attractive to other secondary insects, such as bark beetles, was not overlooked, but no attacks of this nature were observed.

In conjunction with the forestry departments of Virginia and North Carolina and with the advice of the Northeastern Forest Experiment Station (an epidemic of these sawflies has existed in Maryland for several years), a method for sampling overwintering eggs laid in the needles was developed to help forecast 1959 defoliation. This sampling survey is to be conducted early in 1959, and it is hoped that the data obtained will permit accurate estimates of expected defoliation and also be adaptable to a better sampling scheme.

Florida.--In the fall of 1957, infestations of a sawfly on loblolly pine were observed in small, scattered groups in five counties of north-central Florida. Examination of these areas the following spring revealed that few sawfly specimens could be found, and during the early summer defoliation was not observed. By the first week of August feeding by the first generation had been completed; in September, feeding by second generation larvae was quite noticeable, with the epidemic covering about 10,000 to 30,000 acres in Taylor County. In October it was estimated that approximately 300,000 acres of pine forest in Taylor and Dixie Counties were supporting active sawfly populations. Hatching of the third generation took place in October, after which cooler weather slowed developmental time, so that a few late instar larvae were still feeding in December.

The survey work and help with some of the research findings have been handled mainly by the Florida Forest Service. Members of the Florida State Plant Board, Buckeye Cellulose Corporation, and the Southeastern Forest Experiment Station have assisted in biological observations being conducted under the leadership of Dr. L. A. Hetrick of the University of Florida.

Dr. Hetrick's collections of the adult and larval specimens of sawflies have been identified. Four species of sawflies are involved, the most numerous of which is *Neodiprion excitans*; the others are: *N. lecontei* (the red-headed pine sawfly), *N. abbottii*, and *N. compar*. It is known that the first three species have multiple generations a year, and Dr. Hetrick thinks it is likely that *N. compar* has more than one a year. In addition to these identifications,

specimens of: (1) insect parasites (egg and larval), (2) insect, spider, and mammal predators, and (3) diseased larvae have been collected and identified. The actual percent mortality effected by these agents has not been made, but in some locales the combined effects of all have been extensive. Studies suggest that natural enemies may control the most severe infestations.

PINE REPRODUCTION WEEVILS

Infestations by the pine reproduction weevils were common in pine plantings in recently logged areas. The largest outbreak reported was from northeastern Florida in November, where concentrations of pales weevils, *Hylobius pales*, and the pitch-eating weevils, *Pachylobius picivorus*, were observed on 1,000 of some 12,000 acres of concentrated slash pine plantations; heavy injury took place on about 200 acres. The removal of residual seed trees and unmerchantable material during the summer probably served as the attracting force for the weevil populations. Damage to 1- and 2-year-old seedlings was heavy enough to require replanting. Older seedlings, though attacked, were large enough to withstand mortality.

PINE TIP MOTHS

Although no formal surveys were conducted in the Southeast for tip moth infestations, reports of their activity were received from all states in the territory. These insects, which affect the rate of terminal growth, are quite important to young plantations of the southern pines. Studies to investigate many of the unknown biological factors and means of control are under way at Forest Service laboratories in Macon, Georgia, and Gulfport, Mississippi, and on university and industrial experimental forests.

ELM SPANWORM

Hardwood defoliation by the elm spanworm in the mountains of Georgia, Tennessee, and North Carolina in 1958 occurred on some 570,000 acres during May and June. This was an increase of 270,000 acres over that of 1957. The forests of northern Georgia, where the elm spanworm was first found in 1954, suffered less extensive feeding than in previous years. Table 2 shows how the epidemic has increased in size every year since its inception.

The epidemic this year was again characterized by heavy feeding on the ridge tops, with heaviest attacks occurring on the hickories and the oaks. Deterioration and even mortality to the favored hosts has taken place in the areas which have supported populations of the insect for the past 5 years. In addition, studies have shown that measurable growth loss has been effected on the host trees.

Table 2.--Elm spanworm defoliation in the southern Appalachian Mountains, 1954-1958

Year	Class of defoliation			
	Light	Moderate	Heavy	Total
	Acres			
1954 [1]	--	--	--	--
1955	--	--	1,500	1,500
1956	10,000	39,500	1,500	51,000
1957	200,000	81,000	19,000	300,000
1958	425,000	114,000	31,000	570,000

1/ In 1954, defoliation was first found in local concentrations in Georgia.

Moths were observed during late June and July in large numbers in cities and towns as far as 60 miles to the east and south of the infested area. Unless some natural adverse factors are exerted against the spanworm, and to date the extent of such factors observed has appeared to be negligible, it is quite possible that defoliation may increase substantially in 1959.

In a pilot test in the spring of 1958, the aerial spraying of six 50-acre plots in north Georgia with 1 pound of DDT in 1 gallon of kerosene per acre resulted in 99-percent control.

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Testing the TBM Aerial Tanker in the Southeast

by

Theodore G. Storey, George W. Wendel, and Anthony T. Altobellis

U. S. DEPARTMENT OF AGRICULTURE - FOREST SERVICE

Southeastern Forest Experiment Station

Asheville, N. C.

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Director

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The successful use of aircraft for delivering suppressants and retardants on wildland fires in the West led to the tests reported in this paper. It seemed reasonable that if delivery equipment and techniques, developed principally in California, could be used in rugged western terrain, they could be even more useful in the relatively flat terrain of the Southeast. Accordingly, a U. S. Forest Service TBM tanker was obtained on loan in January 1958 for calibration tests in the South by the Southeastern Forest Experiment Station and for cooperative training on test fires by the U. S. Forest Service, Region 8; North Carolina Division of Forestry; and the Georgia Forestry Commission. The aircraft was available operationally for most of the spring fire season; but because a wet spring lowered fire incidence, it was not used on any wildfires.

Most of the operational drops in the West were on wildfires in brush and grassy fuels that had little or no timber overstory. Consequently, no information was available about the amount and distribution of slurry[1] that could be expected to reach surface and understory fuels in timbered stands. The two objectives of this study were: (1) to determine through calibration tests the distribution and penetration patterns of slurry drops from a TBM in pine timber types with and without understory vegetation, and (2) to make preliminary evaluation of the effectiveness of TBM-delivered borate and wet water[2] in retarding or suppressing test fires in several major fuel types.

THE CALIBRATION TESTS

A series of calibration test drops were made on eight representative fuel types in Georgia and North Carolina, in order to determine the extent of crown penetration and distribution of fire retardants dropped from a TBM tanker (table 1).

The Georgia types, which included an open field, two slash pine plantations of different stocking, and a dense natural stand of slash pine reproduction, were located on the George Walton Experimental Forest. Only very sparse understory vegetation was present under the Georgia types, and pine litter covered the ground. A 15-year-old slash pine plantation with 400 stems per acre is shown in figure 1 and the slash pine reproduction in figure 2.

1/ Slurry is a soupy mixture of kaolin, borate, or similar substances and water.

2/ Solution of liquid wetting agent and water.

The North Carolina tests were carried on in four of the heaviest and most widespread fuel types in the coastal plain. All four had a pond pine overstory and a dense understory vegetation (figures 3, 4, 5, and 6). The low and high pocosin[3] types were located in the Croatan National Forest and two cane types were on the Hofmann Forest. Fires in these four types are difficult to control, because of the density of the understory vegetation, large blocks unbroken by natural barriers, and poor trafficability.

Table 1.--Fuel types on which calibration drops were made

GEORGIA

Name (and fuel type)	Description	Overstory				Average shrub height
		Stems per acre	Average height	Age	Crown closure	
		Number	Feet	Years	Percent	Feet
Open field (A)	Grass and broomsedge cover	--	--	--	--	--
Slash pine plantation (B)	Initial spacing 15' x 15', no understory vegetation	325	55	20	64	--
Slash pine plantation (C)	Initial spacing 10' x 10', no understory vegetation	400	45	15	69	--
Slash pine reproduction (D)	Slash pine reproduction, uneven distribution, varying heights	1,400	25	10	66	--
EASTERN NORTH CAROLINA						
Low pocosin (E)	Pond pine overstory, brush, principally ericaceous, dense, easy to walk in	40	10	--	Open	2.5
High pocosin (F)	Pond pine over dense brush, chiefly gallberry, smilax, bay, and cane, very difficult to walk in	200	40	25	50	10
Open cane (G)	Pond pine over reeds, grasses, beakrushes, chiefly with some gallberry, very easy to walk in	20	25	--	Open	4
Overstoried cane (H)	Pond pine overstory, largest percent of understory in cane with some gallberry, smilax, with considerable pine needle drape, difficult to walk in	200	35	20	50	7

3/ In the Southeast, pocosin means "swamp-on-a-hill." High and low refer to the height of the pond pine overstory.

Figure 1.—Fifteen-year-old slash pine plantation. There are 400 stems per acre and crown closure averages 69 percent.

Figure 2.—Ten-year-old slash pine reproduction stand. There are 1,400 stems per acre and crown closure is 66 percent.

Figure 3.—Low pocosin type.

Figure 4.—High pocosin type.

Figure 5.—Open cane.

Figure 6.—Overstoried cane.

Equipment and Material Used

The aerial tanker used in the tests was a single-engine torpedo bomber (TBM) of about 2,000 horsepower, formerly used by the Navy and now converted to drop liquids (1, 8, 9). With the bomb bay fittings and doors removed, the interior of the plane was fitted with a two-section aluminum tank having an approximate capacity of 440 gallons. Two hinged doors, each about 900 square inches in area, made up almost the entire bottom of the tank. They were hydraulically operated and were actuated by a pilot-controlled electric release mechanism. They could be operated singly or simultaneously and could be closed in flight when the sections were empty.

The material used for the calibration tests was a kaolin slurry made by mixing 1,250 pounds of kaolin (KCS Hydrite) with enough water to prepare 440 gallons. Kaolin slurry has approximately the same consistency as borate slurry, is cheaper than borate, and adheres well to vegetation. When dry it is much whiter than borate and thus offers a distinct advantage in observing test patterns.

Procedure

In Georgia, three rectangular plots 120 feet by 288 feet were laid out in each fuel type. Each plot was divided into a grid of rectangles 18 feet by 20 feet. Pre-weighed, paraffin-coated paper cups, 6 inches in diameter, were placed at the grid intersections. No attempt was made to place all the cups under the same crown closure. Flags were fastened to treetops at one end of the grid to aid the pilot. After each drop the cups were re-weighed and the application rate in gallons per 100 square feet was determined for each cup location.

Three drops were made in each of the Georgia types:

1. Single 220--only 220 gallons released.

2. Double 220--two drops of 220 gallons were released with one superimposed on the other in successive runs.

3. Single 440--440 gallons released at one time.

So far as possible, the tests were conducted under uniform operating conditions (table 2). The plane was operated at a speed of 115 miles per hour at optimum altitude during release. Operational days were confined to those with surface winds 10 miles per hour or less and days when the vegetation foliage was dry.

The procedure used in North Carolina was basically the same as that in Georgia except that the cups were set at a grid spacing of 18 feet by 18 feet. Also the length of the grid was increased to 396 feet, because it was noted that the pilot sometimes overshot the shorter grid in Georgia. Instead of flags to mark the plot for the pilot, two weather-type balloons 3 feet in diameter were

suspended on either side of the grid at its midpoint. Only 440-gallon drops were made in North Carolina.

Results

A single 220-gallon drop on an open field (Type A) from an altitude of 75 feet gave a pattern 350 feet long and 80 feet wide (table 3, figures 7 and 8). A similar drop from an altitude of 70 feet on a slash pine plantation with no understory (Type C) gave a pattern 360 feet by 72 feet. Although the patterns do not differ greatly in dimensions, 86 percent of the load reached the ground in a readily observable pattern in Type A, whereas only 61 percent reached the ground in Type C. The difference in total gallons represents the amount of kaolin retained on the pine crowns in Type C.

Table 2.--Operational data for TBM kaolin calibration tests in Georgia and North Carolina, 1958

Drop number	Date	Fuel	Load	Flight direction	Height of plane 1/	Wind: Direction	Wind: Speed	Relative humidity	Air temperature	Accuracy
		Type	Gallons		Feet		Miles per hour	Percent	Degrees F.	
1	Feb. 10	A	220	N-S	75	NW	6	35	48	Good-left
2	Feb. 12	A	Double 220	N-S	50	N	5	36	41	Good-left
3	Feb. 10	A	440	N-S	85	NW	5	33	48	Long-left
4	Feb. 20	B	220	S-N	75	SW	7	43	47	Good
5	Feb. 5	B	Double 220	W-E	85	SW	8	45	65	Long-left
6	Feb. 20	B	440	S-N	75	SW	4	55	40	Good
7	Feb. 12	C	220	E-W	70	NW	6	29	46	Good
8	Feb. 12	C	Double 220	S-N	70	NNW	7	28	48	Long-right
9	Feb. 12	C	440	N-S	60	N	4	29	45	Good-left
10	Feb. 21	D	2/ Double 220	SW-NE	60	SW	2	58	38	Good-left
11	Feb. 21	D	440	NE-SW	75	SW	3	49	44	Long-left
12	Mar. 24	E	440	NE-SW	100	W	13	--	55	Good-long
13	Mar. 24	F	440	SW-NE	100	NE	7	--	55	Good-right
14	Mar. 28	G	440	SW-NE	76	NW	7	46	58	Good-long
15	Mar. 28	H	440	SW-NE	91	NW	3	44	55	Good

1/ Above ground. All drops at 115 miles per hour air speed.
2/ The single 220 drop in Type D was omitted because of poor accuracy of the drop.

Table 3.--Results of calibration tests in Georgia and eastern North Carolina

Drop (amount)	Fuel[1/]	Contour line[2/]	Area between adjacent contour lines	Length of pattern	Average width of pattern	Amount of slurry on ground: Approx. total	Amount of slurry on ground: Total load
	Type	Gallons per hundred square feet	Square feet	Feet	Feet	Gallons	Percent
220	A	0.0	24,105	350	80		
		.5	6,687	252	54		
		1.0	3,525	162	30		
		2.0	1,555	80	15	192	86
Double 220	A	.0	10,523	360	72		
		.5	8,139	342	54		
		1.5	5,391	288	22		
		2.0	3,110	189	18		
		3.0	1,037	144	7	287	65
440	A	.0	25,142	378	90		
		.5	5,184	252	54		
		1.0	4,043	216	36		
		1.5	2,333	189	27		
		2.0	985	144	15		
		2.5	778	72	5	234	53
220	B	.0	--	--	--		
		.25	4,014	162	70		
		.50	3,740	126	50		
		1.00	1,267	54	40		
		2.00	228	25	10	(3/)	(3/)
Double 220	B	.0	--	--	--		
		.5	5,184	216	50		
		1.0	2,229	180	18		
		1.5	1,710	170	15		
		2.0	1,296	108	10	(3/)	(3/)
440	B	.0	15,707	360	80		
		.50	5,288	306	25		
		1.00	3,940	216	20		
		2.00	1,502	126	18		
		3.00	574	60	5	192	44
220	C	.0	21,410	360	72		
		.50	4,510	216	27		
		1.00	1,814	126	19		
		2.00	1,192	45	15	135	61
Double 220	C	.0	--	--	--		
		.5	8,502	306	54		
		1.0	2,903	180	45		
		1.5	2,488	160	20		
		2.0	829	140	10	(3/)	(3/)

Table 3. --Results of calibration tests in Georgia and eastern North Carolina (cont'd)

Drop (amount)	Fuel[1/]	Contour line[2/]	Area between adjacent contour lines	Length of pattern	Average width of pattern	Amount of slurry on ground: Approx. total	Amount of slurry on ground: Total load
	Type	Gallons per hundred square feet	Square feet	Feet	Feet	Gallons	Percent
440	C	0.0	17,107	369	81		
		.5	8,294	234	54		
		1.0	3,888	198	15		
		2.0	518	54	9	173	39
Double 220	D	.0	16,485	342	72		
		.5	5,547	252	45		
		1.0	3,266	198	20		
		2.0	1,555	126	15	163	37
440	D	.0	--	--	--		
		.5	4,873	252	36		
		1.0	2,229	198	18		
		1.5	1,552	126	10	(3/)	(3/)
440	E	.0	17,314	378	72		
		.5	7,154	252	47		
		1.0	3,473	189	25		
		1.5	1,037	72	18	155	35
440	F	.0	9,643	351	81		
		.25	8,605	252	72		
		.50	4,976	207	27		
		1.00	2,022	180	10	101	23
440	G	.0	11,664	342	90		
		.5	10,524	288	54		
		1.0	3,784	126	36		
		1.5	1,140	108	15	171	39
440	H	.0	13,219	360	75		
		.5	9,383	297	54		
		1.0	4,510	216	36		
		1.5	1,867	162	14		
		2.0	414	79	12	200	45

1/ Refers to types described in table 1. The single 220 drop in Type D was omitted because of poor accuracy of the drop.

2/ Lines of equal kaolin concentration. The zero contour line represents the outer limit of visible kaolin coating on the surface litter.

3/ Indeterminate because a large portion of the outermost contour line fell outside the cup grid.

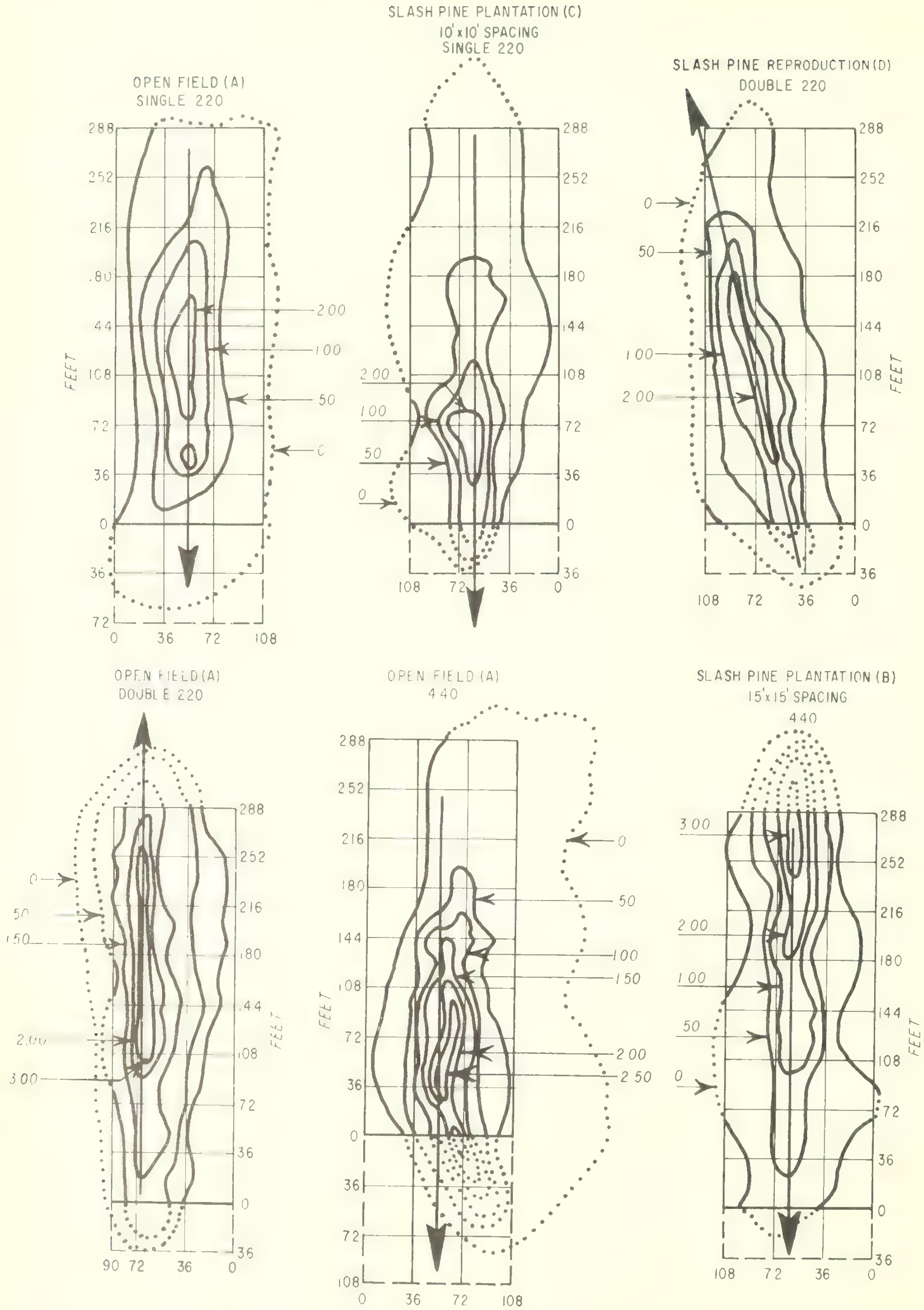

Figure 7.—Sample distribution patterns of calibration tests in Georgia. Contour lines represent concentration of kaolin in gallons per 100 square feet. Heavy arrows indicate direction of flight. Dotted portions of patterns are estimated.

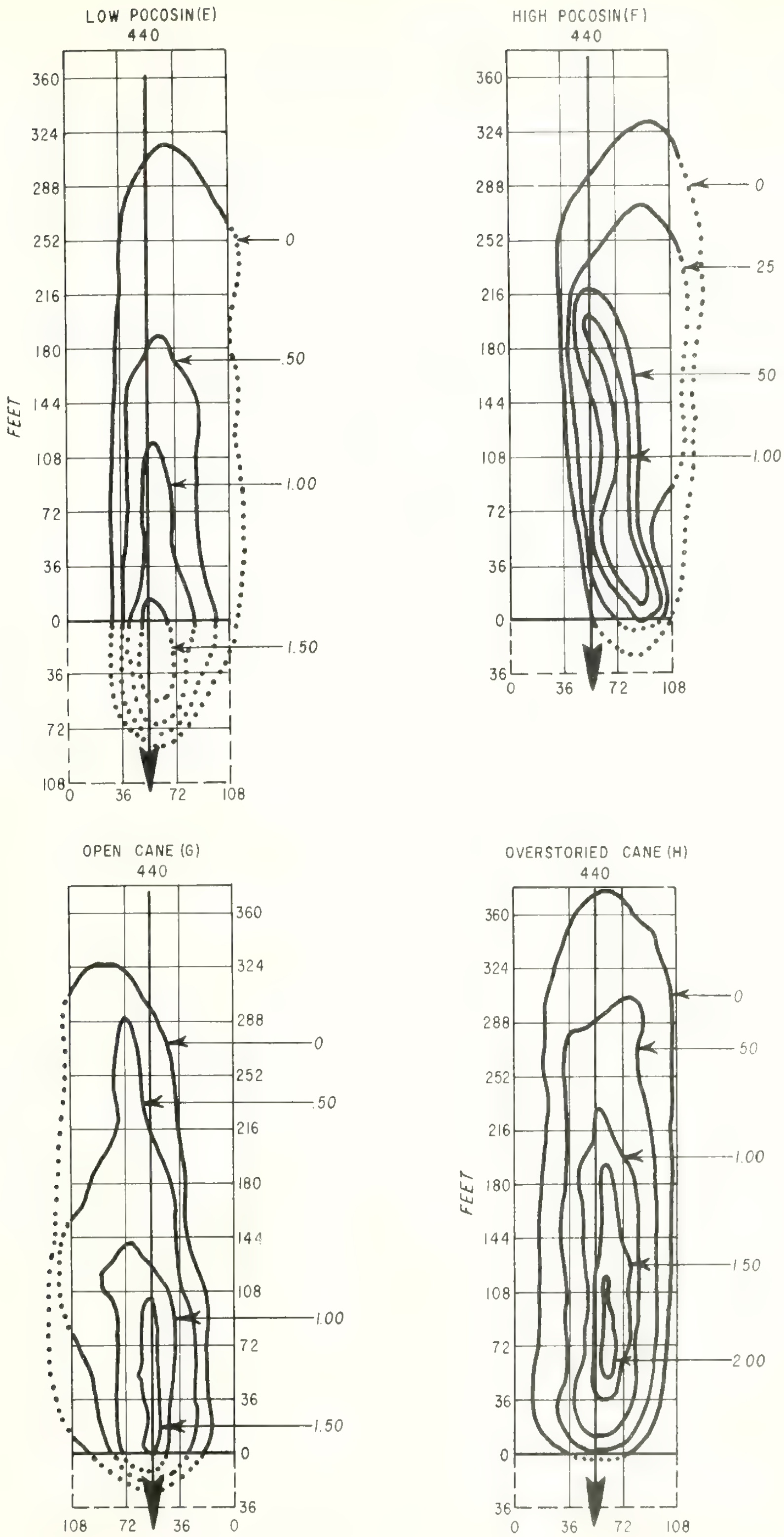

Figure 8.—Sample distribution patterns of calibration tests in North Carolina. Contour lines indicate concentration of kaolin in gallons per 100 square feet. Heavy arrows indicate direction of flight. Dotted portions of patterns are estimated.

A comparison of the 440-gallon drops in Types B, C, E, F, G, and H with a 440-gallon drop in Type A shows that the over-all pattern size remains fairly constant even though the altitude from which the drops were made varied between 60 and 100 feet. About 53 percent of the total load reached the ground in the open (Type A), whereas the amount that reached the ground in Types B, C (slash pine types), and E, F, G, and H (pond pine types) were 44, 39, 35, 23, 39, and 45 percent of the total load, respectively. The differences in the amounts that reached the ground in the several vegetation types and in the open area represent the amount of slurry which was retained on the overstory and understory vegetation. Figures 9 through 13 give an indication of the extent of kaolin slurry coating in some of the North Carolina types.

A double 220-gallon drop in the open from an altitude of 50 feet gave a pattern 360 feet long and 72 feet wide. A similar drop in Type D gave a pattern 342 feet long and 72 feet wide. Sixty-five percent of the total load reached the ground in the open whereas only 37 percent of the total load reached the ground in Type D.

Discussion

It is evident from the results that in all types the over-all pattern size for 220, double 220, or 440 gallons does not vary greatly. The variations in the size of the several patterns may be attributed to varying air speed, differences in drop altitude, crabbing of the airplane, wind, and accuracy (in the case of the double 220-gallon drops).

In Types B, C, and D, which are slash pine stands of various ages, spacings, and densities but with similar crown closures, the percent of the total load that reached the ground, with one exception, varied only by 7 percent.

Even though the overstory crown closure was less in the North Carolina pocosin and cane types, slightly less slurry reached the ground than in the Georgia slash pine types. The reduction was due to the dense shrub and cane vegetation under the North Carolina types. Almost complete coating of the understory was observed in an area 250 feet long by 40 feet wide, or roughly the area encompassed by the 0.5 gallon per 100 square feet kaolin contour. In Types E and F (low and high pocosin), which have a predominantly broad-leaved shrub understory, less slurry reached the ground than in Types G and H (cane types), which have a larger percentage of canes and grasses in the understory. Probably the more vertical habit of the canes and grasses permitted a larger amount of the slurry to reach the ground.

Although the test results indicate the application rates of kaolin slurry that penetrated different fuel types, they do not offer any information about the minimum application rates necessary to retard or extinguish fires in these types. With this in mind, a series of test fire drops were planned on Types E, F, G, and H in eastern North Carolina.

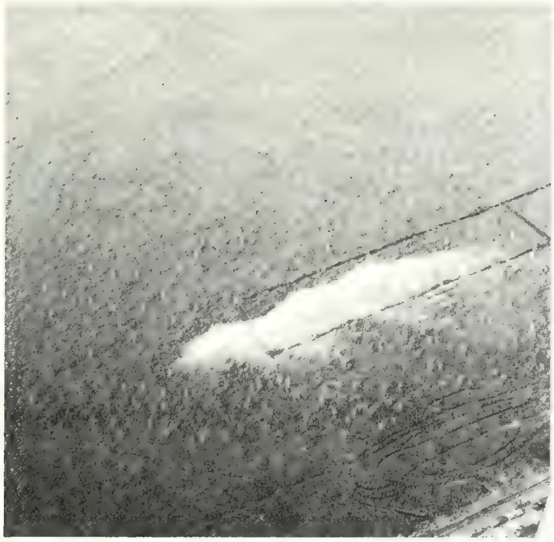

Figure 9.—Aerial view of low pocosin type after a drop of 440 gallons of kaolin slurry. (N. C. Division of Forestry photo.)

Figure 10.—Aerial view of high pocosin type after a drop of 440 gallons of kaolin slurry. (N. C. Division of Forestry photo.)

Figure 11.—Open cane after 440-gallon kaolin calibration drop. (N. C. Division of Forestry photo.)

Figure 12.—Overstoried cane after 440-gallon kaolin calibration drop. (N. C. Division of Forestry photo.)

Figure 13.—Low pocosin type, showing extent of kaolin slurry coating from a 440-gallon drop.

DROPS ON TEST FIRES

Procedure

One borate plot and one wet-water plot, each approximately 400-feet square, were laid out in the four fuel types in North Carolina. One or more firelines were plowed around each plot to provide fire protection and to define the plots for the pilot.

The borate slurry used in the test fire drops was prepared in 440-gallon batches by mixing approximately 1,600 pounds of borate with water in an injector mixer as described by Miller and Wilson (6).

The wet-water solution was prepared by adding one quart of a liquid wetting agent to a 440-gallon load of water. Vibration of the aircraft served to mix the chemical adequately. The solution approximated the heaviest concentration recommended by the manufacturer to obtain deep penetration of forest fuels.

The borate drops were planned to simulate indirect attack. Consequently, the borate line was laid down from 15 seconds to 20 minutes prior to arrival of the flame front. The wet-water drops were made on the flame line to simulate direct attack.

Burning Conditions

The fire drop tests were conducted on two afternoons between 1:30 p. m. and 6:45 p. m. when fire danger was medium (table 4). Air temperatures ranged from 60° to 80° F. and relative humidities were between 24 and 39 percent. Wind was steady from the NE and ranged up to 8 m.p.h. Fuel moistures did not exceed 7 percent. Ground water tables were near the surface and water was standing in the plowed firelines. All plots except the borate plot in the low-pocosin type were easily ignited. Fire spread rapidly from the start; and, in the case of the wet-water plots, it was necessary to have the air tanker circling overhead as a precautionary measure before fires were set. In all cases, however, fires had gained maximum intensity before reaching the treated lines. The fires ranged in intensity from low-medium to high-medium except for one which was very low intensity (table 5).

Results and Discussion

In all fire tests the drops were placed with sufficient accuracy to provide useful information on their effectiveness in retarding and suppressing fire. Both the borate and wet-water patterns appeared to be similar to the calibration patterns found for kaolin for equal loads dropped in similar fuel types.

Table 4. --Operational data for TBM borate and wet-water drops on test fires in North Carolina, 1958

Fuel type	Date	Air temperature	Relative humidity	Wind: Direction	Wind: Velocity	Fuel moisture	Fire danger: Buildup index 8-100-0	Fire danger: Burning index 8-100-0	Time: Fire set	Time: Drop	Height of plane [1]
		Degrees F.	Percent		Miles per hour	Percent					Feet
E	Apr. 18	70	--	--	0	[2] 5.5	[2] 6	[2] 1	6:45 p.m.	6:46 p.m.	80
E	Apr. 18	77	32	NE	3	5.5	6	5	5:20 p.m.	[3] 5:30 p.m. 5:33 p.m.	80 80
F	Apr. 18	75	32	NE	2-3	4.5	6	7	3:11 p.m.	3:10 p.m.	85
F	Apr. 18	80	32	NE	4.5	4.5	6	10	4:20 p.m.	4:30 p.m.	90
G	Apr. 10	[4] 73	[4] 24.5	[4] NE	[4] 8	[4] 7	[4] 10	[4] 16	1:40 p.m.	1:50 p.m.	100
G	Apr. 10	69	32	NE	3	7	10	16	3:15 p.m.	3:18 p.m.	80
H	Apr. 10	60	39	NE	1-2	6	10	16	5:10 p.m.	4:45 p.m.	75
H	Apr. 10	60	39	NE	8	6	10	8	5:50 p.m.	6:00 p.m.	80

1/ Above ground. All drops at 115 miles per hour air speed.

2/ Deppe fire danger station 10 miles away. 2:00 p. m. buildup index. Burning index and fuel moisture at time fire set. Other weather measurements on site.

3/ Double 220-gallon drop.

4/ Portable fire danger station on site. 2:00 p. m. buildup index. Other weather measurements at time fire set.

Table 5. --Results of TBM borate and wet-water fire drop tests in North Carolina, 1958

Fuel type	Date	Material dropped		Type of fire	Average flame height above ground	Estimated fire intensity 1/	Relative fire intensity	Effective line			
		Name	Amount					Retarded	Estimated minimum application rate	Extinguished	Estimated minimum application rate
			Gallons		Feet	B.t.u. per second per foot		Feet	Gallons per 100 sq. ft.	Feet	Gallons per 100 sq. ft.
E	Apr. 18	Borate	440	Head	1	6	Very low	2/ 300	0.5	2/ 300	0.5
E	Apr. 18	Wet water	220 220	Head	12	770	Low-med.	3/ 200 200	.8 .8	3/ 200 200	.8 .8
F	Apr. 18	Borate	440	Head	25	2,100	Med.	250	.3	230	.4
F	Apr. 18	Wet water	440	Flank-head	25	2,100	Med.	300	.2	250	.3
G	Apr. 10	Borate	440	Head	20	2,400	Med.	300	.4	250	.6
G	Apr. 10	Wet water	440	Flank	20	2,400	Med.	300	.5	280	.6
H	Apr. 10	Borate	440	Head	15	520	Low-med.	300	.5	280	.6
H	Apr. 10	Wet water	440	Flank	25	3,100	High-med.	350	.2	300	.5

1/ From the equation $h = 0.45\ I^{0.46}$, where h = flame height in feet and I = fire intensity in B.t.u./sec./foot of fire front. This equation appears in chapter 3, "Combustion of Forest Fuels," by G. M. Byram, in the book Forest Fire Control and Use by K. P. Davis.

2/ Full pattern was effective because of low fire intensity.

3/ Drops laid end to end totaling 400 feet of effective line.

In the high-pocosin type, which is rated a heavy fuel in North Carolina, borate retarded 250 feet and extinguished 230 feet of medium-intensity headfire. The minimum application rates of borate via airdrop to ground needed to retard and extinguish this much line were estimated to be about 0.3 gallon and 0.4 gallon per 100 square feet, based on the calibration drops. In the overstoried cane (which is also a heavy fuel), borate retarded 300 feet and extinguished 280 feet of low-medium intensity headfire. Minimum application rates were estimated to be 0.5 and 0.6 gallon per 100 square feet, respectively.

A 440-gallon load of borate dropped in the open cane, a medium fuel, retarded 300 feet and extinguished 250 feet of medium-intensity headfire. Estimated minimum application rates necessary to achieve these results were 0.4 and 0.6 gallon per 100 square feet, respectively. In the low pocosin type, with a fuel volume similar to the open cane type, fire was extinguished over 300 feet of line (nearly the full length of the borate pattern) because unfavorable burning conditions produced a fire of very low intensity.

In all four fuels, pattern widths were observed to be more than adequate to stop the test headfires of all intensities. In no case was there a gap in the pattern large enough to allow the test fires to cross into uncoated fuels.

In both medium and heavy fuels, fire was crowning along portions of the line when it reached the borate-treated strip. In no case did fire carry through the crowns past the treated strip.

The fire-retardant properties of borate were well demonstrated in the high pocosin type. Immediately after the drop, a fire was set about 100 feet upwind of the retardant line. The fire moved rapidly through the dense 7-foot tall underbrush and often ran to and above the crowns of the 35-foot pond pines. The average flame height was 25 feet above ground. When the fire reached the borate line, it quickly dropped to the ground and crept along until finally it was extinguished by the coated fuel. This decrease in flame height corresponds to a reduction in fire intensity from approximately 2,100 B. t. u. per second per foot of fireline (medium intensity) to essentially zero in just a few minutes. Figures 14, 15, and 16 show the sequence of events during indirect attack on fire in open cane.

Figure 14.—Open cane in the borate fire test plot. The loaded TBM is just arriving. Flames average 20 feet high. (N. C. Division of Forestry photo.)

Figure 15.—Open cane in the borate fire test plot. The TBM pilot has just released his 440-gallon load aimed just ahead of the fire. Altitude 100 feet above ground. (N. C. Division of Forestry photo.)

Figure 16.—Open cane in the borate fire test plot about two minutes after drop. Fire has burned into borate line and is fairly well controlled in the area visible in the picture. (N. C. Division of Forestry photo.)

Figure 17.–Open cane in the wet-water fire test plot. The pilot has just released his 440-gallon load aimed directly at the line of 20-foot flames marked by light smoke. The fire was burning hot with little smoke. (N. C. Division of Forestry photo.)

Results of the wet-water drops in direct attack were similar to the results from the borate drops for similar fuels and fire intensities (table 5). In heavy fuels, wet-water drops retarded an average of 325 feet and extinguished 275 feet of medium-intensity flank fire. Estimated minimum application rates 4/ of wet water to retard and extinguish fire were 0.2 and 0.4 gallon per 100 square feet. The wet-water drop in the open cane, a medium fuel, retarded 300 feet and extinguished 280 feet of medium-intensity flank fire. Minimum application rates to retard and extinguish fire were estimated to be 0.5 and 0.6 gallon per 100 square feet, respectively. Crown fire was knocked to the ground and was extinguished within the effective pattern area (figures 17, 18, and 19).

In all of these tests borate and wet water retarded and extinguished approximately equal lengths of fire front in similar fuel types (table 5); however, timing was somewhat different. Fire burning into a borate line was knocked to the ground and then gradually decreased in rate of spread and intensity until finally it was extinguished; wet water dropped directly on the flame line achieved about the same results almost immediately. Of course borate can also be used in direct attack, but it is considerably more expensive than wet water. One of borate's values lies in the residual coating of retardant left on the fuels after the water in the slurry has evaporated.

Figure 18.—Open cane in the wet-water fire test plot. Cloud of wet water is settling over the fireline enveloping it almost completely. (N. C. Division of Forestry photo.)

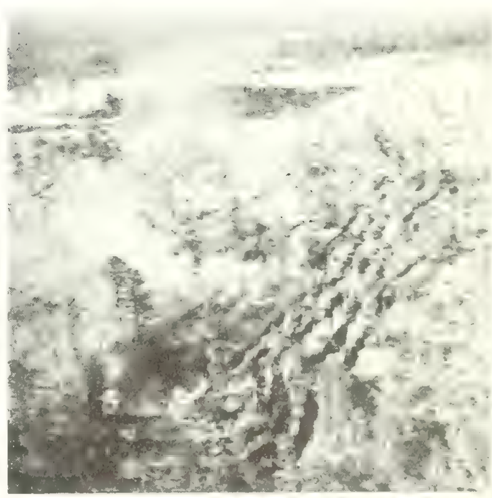

Figure 19.—Open cane in the wet-water fire test plot one minute after drop. Fire almost completely extinguished within pattern. (N. C. Division of Forestry photo.)

4/ Based on kaolin calibration tests.

In the low-pocosin type, two 220-gallon loads of wet water laid end to end in quick succession were dropped on a line of fire 400 feet long. The two drops together knocked down and extinguished a substantially greater length of line (400 feet) than a single 440-gallon drop (up to 300 feet). The width of pattern of each 220-gallon drop was adequate to extinguish the depth of fire front in this type with a margin of safety.

Two additional fire drops with borate were made on March 1 near Waycross, Georgia, in a medium-stocked stand of longleaf and slash pine with predominantly palmetto-gallberry understory. Although general weather conditions were similar to those for the North Carolina pine drops, the ground fuel (litter) was considerably drier. Carrying a full load of 440 gallons, the TBM laid a borate swath about 75 feet ahead of a flank fire by dropping half its load end-to-end in each of two runs. A similar pattern was laid in front of a head fire. Both fires were of about equal intensity, advancing at the rate of 5 chains per hour.

Only the very center of each drop pattern, an area encompassing 1,000 to 2,000 square feet, actually stopped the advancing fire. Palmetto fronds in this area were heavily coated with borate and although the application rate on the surface litter under the palmetto was less, the fuel was well covered. The fire was cooled in the remaining pattern area and brought down from the palmetto fronds to the pine needle litter on the ground but the fire continued to advance, though at reduced intensity.

The penetration rate of aerial slurries through palmetto-gallberry fuels was not calibrated; however, observations showed considerably more borate was intercepted than in other understory brush species tested. This was largely due to the protective effect of the palmetto fronds. Consequently, patterns of equal application rates for equal loads and lengths of fireline extinguished and retarded were shorter in the Georgia palmetto fuels than in the broadleaf brush fuels in North Carolina.

CONCLUSIONS

1. Equal volumes of borate and of wet water in similar fuels retarded and suppressed approximately equal lengths of fireline. However, because borate was not delivered on test fire fronts, a direct comparison of the effectiveness of borate slurry and wet water cannot be made.

2. Wet water and borate may be about equally effective for direct attack on low to medium intensity fires. However, for wet water to be as effective as borate it would have to be dropped on or close in front of the fire, because wet water will evaporate relatively quickly. The pilot must have an unobstructed view of the flame line when dropping wet water.

3. Borate probably would be more effective than wet water for indirect attack when the retardant line is laid down ahead of the flame line; also, for direct attack on days when the flame line is obscured by smoke and there is a chance that the pilot might overshoot his target.

4. Effective lines from which to backfire can be built from the air in light, medium, or even heavy fuels with either 220- or 440-gallon loads of borate slurry.

We realize that the air tanker is only another tool in fire control. However, in inaccessible areas or where trafficability is poor, air tankers with a capacity of 400 gallons or less may be effective in extinguishing small fires and containing larger fires of medium intensity until ground equipment can arrive. Planes such as the Stearman and N3N, with capacities of 100-125 gallons, have been used successfully in the West (2, 3, 5). Certainly they deserve an adequate trial in the South. Relatively flat topography and numerous small airstrips would make their potential even more promising. As in the West, Stearman-type aircraft are used extensively in the South for agricultural flying and presumably would be available on a contract basis.

Other small aircraft, such as float-type planes, have been successfully used in Canada (7) and the United States (4). Perhaps in the Southeastern coastal plain, where there are numerous lakes, rivers, and sounds, this type would be effective.

Larger aircraft with 1,000 to 2,000 gallon capacity also deserve to be tried. The PBY, for example, has been used successfully in California (1). It should be even more effective in the Southeast, where topography is much less of a problem.

Because these tests were exploratory in nature, no attempt was made to keep detailed time and cost figures. However, cost-benefit considerations will ultimately determine whether or not aerial fire suppression methods will be used in the Southeast, and also how extensively.

SUMMARY

In the spring of 1958, 15 calibration drops of kaolin slurry from a TBM tanker were made in natural and planted pine timber types in the coastal plain of North Carolina and Georgia. In addition, the effectiveness of borate and of wet-water drops was observed on test fires in coastal North Carolina. Two additional borate fire drops were made in palmetto-gallberry fuels in Georgia.

Over-all pattern size for 220-, double 220-, or 400-gallon kaolin calibration drops made from altitudes between 50 and 100 feet above ground was about 370 feet by 75 feet in all fuel types. Patterns were fairly uniform with no gaps of low concentration.

The amount of slurry that reached the ground in a readily discernible pattern varied with the size of load, height of drop, cover type, and wind velocity. In the open, 86 percent, 65 percent, and 53 percent of 220-, double 220-, and 440-gallon loads, respectively, reached the ground. The low proportion of slurry measured from the 440-gallon drop in the open probably was caused by the 10- to 35-foot greater drop height compared to the other two drops in the open. Catch for 440-gallon drops averaged 41 percent under medium-density pine plantations with no understory, 37 percent under open pond pine with dense understory vegetation, and 34 percent for medium-dense pond pine stands with dense understory. The differences in amounts reaching the ground in the several types, as compared to the open, represent the amounts retained on the overstory and understory vegetation. Almost complete coating of the understory vegetation and surface litter was observed where the application rate on the ground was about 0.4 gallon or more per 100 square feet.

In the fire drop tests, indirect attack with 440 gallons of borate slurry retarded an average of 275 feet and extinguished 255 feet of medium-intensity headfire, in medium-dense pond pine timber with dense brush and reed understory. Estimated minimum application rates on the ground of about 0.4 and 0.5 gallon per 100 square feet were required to achieve these results.

Borate drops on fires similar to those mentioned above but in very open pond pine timber with dense brush and cane understory retarded 300 feet and extinguished 275 feet of fireline. Estimated minimum application rates to retard and extinguish fire were 0.5 and 0.6 gallon per 100 square feet, respectively. These estimates are not applicable to palmetto-gallberry fuel types of the coastal plains, where heavier application rates are apparently needed.

Direct attack with 440 gallons of wet water achieved about the same results as indirect attack with borate in similar fuel types and under similar burning conditions. Minimum application rates were approximately the same for both agents.

Two 220-gallon loads of wet water laid end to end extinguished a total of 400 feet of medium-intensity headfire or 200 feet on each pass in medium-density fuels.

Pattern widths for both 220- and 440-gallon loads appeared to be sufficiently wide to retard and extinguish specified lengths of line in the four fuel types. In no case was there a gap in the pattern wide enough to allow fire to cross into uncoated fuel.

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Site Treatment Reduces Need for Planting at Loblolly Harvest Time

by

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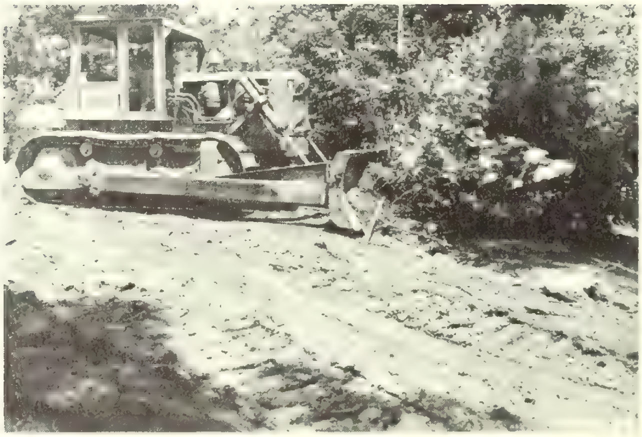

Site Treatment Reduces Need for Planting at Loblolly Harvest Time

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Kenneth B. Trousdell

Intensive research for more than a decade has shown that natural regeneration of loblolly pine after commercial harvest is usually possible, and with planning usually successful, in the coastal plain of Virginia and the Carolinas.[1/] Nevertheless, poor seed years, difficult conditions, a desire to insure the reproduction of valuable stands, and various other reasons have of late years led a number of large landowners to try planting after harvest as a method of forest regeneration. The area (well stocked as a rule) is logged, in some cases it is disked or bulldozed, the hardwoods may or may not be poisoned, and then the nursery seedlings are planted by hand.

Because most of these plantations are as yet under 5 years of age, little has been known of the effectiveness of this method of regeneration. Whether such plantings are necessary has been something of a question too. Consequently, this paper reports an exploratory survey of 3-year-old plantations established in 1954-1955. It supplies some information and evaluates practices and factors that affect establishment and growth of planted seedlings, wildings, and the combined new stand.

PLANTING HISTORY AND STUDY METHODS

Planting records for the 1954-1955 season on over 4,000 acres of forest land in seven Virginia counties south of the James River were obtained from three coastal plain pulp companies: Union Bag-Camp Paper Corporation, Continental Can Company, Inc., and Southern Johns-Manville Products Corporation. The plantations were on well drained to imperfectly drained lands. None were on the poorly drained flat lands typical of the eastern part of the coastal plain. Site index estimates ranged from 75 to 90 and averaged 83.

1/ Wenger, Karl F., and Trousdell, Kenneth. Natural regeneration of loblolly pine in the South Atlantic Coastal Plain. U. S. Dept. Agr. Prod. Res. Rpt. 13, 78 pp., illus. 1958.

Three preplanting treatments were studied: no ground preparation, disking before planting, and bulldozing before planting. Plantations established without ground preparation included lands planted on hardwood areas without previous logging, and areas logged before planting. The disking treatments were alike in that all areas were given a single disking rather than the more severe double disking used in later years. Eight of the bulldozed samples were on areas windrowed, while four were not. Hardwoods were generally poisoned except in the windrows on bulldozed areas, where they were inaccessible. Disked and bulldozed areas 4 years after planting are shown in figure 1.

Although all seedlings were bar planted, rate of planting differed with each company; one planted at a spacing designed to establish 800 seedlings per acre, another 900, and the third 1,000. The plantations were established under varying amounts of competition from large trees. Some large hardwoods were not deadened and some were treated but survived. Yellow-poplar was consistently left on all areas, and sweetgum was saved on one ownership. On all lands, residual pines were purposely left untreated; on some areas seed trees were left standing. Small hardwoods and pine were generally not chemically treated, and those trees surviving chemical treatments remained to grow.

Twelve random samples were drawn from plantations within each of the three treatments. Each random field sample consisted of a plot containing 100 milacres. On each milacre the seedlings were counted and classified as either planted or natural. The best prospect of each of these two classes was also classified as free-to-grow or not free-to-grow.[2/] In addition, the height of the tallest planted seedling was measured.

The root systems of planted seedlings were classed as good, L-shaped, J-shaped, or balled. Soil characteristics were related to planted seedling height according to the soil-site classification of Coile.[3/]

Free-to-grow stocking has previously been shown to be related to total stocking and hardwood competition.[4/] Competition 1 inch d. b. h. and larger of both pine and hardwoods was measured by point sampling with a wedge prism, and the pine was separated into two classes, cone bearers and non-cone bearers.

2/ "Free-to-grow" seedlings are seedlings which were not definitely overtopped at the time of measurement and whose height in relation to competing vegetation precluded overtopping during the next growing season.

3/ Coile, T. S. Soil productivity for southern pines. Part I, Shortleaf and loblolly pines. Forest Farmer XI(7): 10, 11, 13. 1952.

4/ See footnote 1.

Figure 1.—Above, Plantation at age 4 in Sussex County, Virginia. Area was logged, disked, planted, and hardwoods poisoned. Below, Plantation at age 4 in Chesterfield County, Virginia. Site was bulldozed, all hardwoods were windrowed, and area planted. Brushy area at right shows the margin of a windrow.

RESULTS

Treatments Had Little Effect on Survival and Development of Planted Seedlings

The tendency of planters to cluster and the presence of obstructions in the form of stumps and slash caused an irregular spacing of planted seedlings. Thus, the spacing of planted seedlings was unlike the regular pattern that characterizes most plantations, and only at the lowest numbers of surviving seedlings per acre did stocking approach regular spacing. The relationship of number of seedlings and their milacre stocking in figure 2 indicates the difficulty of obtaining a high percentage of milacre stocking of planted seedlings under forest conditions.

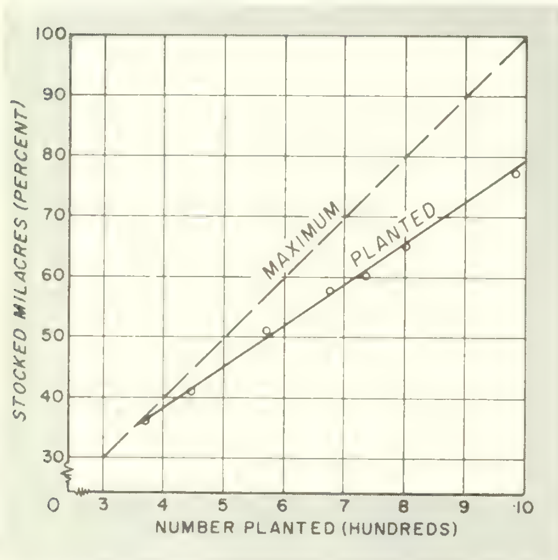

Figure 2.—The level of milacre stocking attained by planting, compared to maximum stocking attainable. Under forest conditions it is difficult to obtain a high percentage of milacre stocking of planted seedlings.

The basal area per acre of pine and hardwood trees 1 inch d. b. h. and larger provided a measure of competition. On the 36 harvested plots, competition varied between 1 and 39 square feet of basal area per acre. The average basal area of this competition was 22 square feet on areas logged without additional treatment, 19 square feet on disked areas, and 16 square feet on bulldozed lands. The effect of residual trees upon planted seedlings is to reduce the percentage of trees that are expected to attain dominance in the stand. On the eight bulldozed areas with windrows, this competition was principally in the windrows.

Variation in number of planted seedlings, in milacre stocking of planted seedlings, and in level of competition was found to be greater within treatment than between treatments. In fact, it appears that the basic treatments per se had little, if any, effect upon either survival or early development of the planted seedlings.

Treatments Had Important Effect on Natural Seedlings

There was a positive correlation between number of natural seedlings and the basal area of cone-bearing pines per acre on all areas.

The larger number of natural seedlings found on bulldozed lands indicates that better and longer-lasting seedbed conditions are provided by this treatment. It was evident from the number of 1- and 2-year-old seedlings on bulldozed lands that seedbeds prepared by bulldozing are good seedbeds for at least 3 years. From other studies[5/] it has been determined that disked, logged, or burned seedbeds are good the first year but become poor seedbeds by the third year.

The best expression of factors influencing free-to-grow stocking of natural seedlings by milacres is:

Free-to-grow stocking by milacres = -2.195 + 1.064(S) - 3.191(B)
where S = total stocking by milacres
B = basal area of all trees 1 inch d.b.h. and larger, coded as follows:
0 to 5 sq. ft. basal area = 1; 5 to 10 sq. ft. basal area = 2; etc.

This expression accounted for 93 percent of the total variation.

Total Seedling Stand

On the average, there were more natural than planted seedlings per acre (table 1). Naturally established seedlings ranged from 50 to 2,870 per acre, with nearly half the plots containing over 1,000 natural seedlings per acre.

Disking and bulldozing increased the total seedling stand and increased both the total and free-to-grow stocking. When planted seedlings were excluded and natural seedlings alone were tallied, the same held true. It is also true that there were fewer cone-bearing pines and a greater basal area of hardwood competition on logged plots with no other treatment than on disked or bulldozed plots.

Table 1.—Number of seedlings, and stocking 3 years after planting, by preplanting treatments

Treatment	Per acre	Total	Free-to-grow
	Number	Percent of milacres stocked	
PLANTED SEEDLINGS			
No treatment	536	48	36
Disked	648	55	46
Bulldozed	555	49	44
Average	579	51	42
NATURAL SEEDLINGS			
No treatment	551	26	19
Disked	688	39	31
Bulldozed	1,360	53	45
Average	866	39	32
ALL SEEDLINGS			
No treatment	1,087	62	47
Disked	1,336	71	59
Bulldozed	1,915	72	63
Average	1,445	68	56

5/ See footnote 1.

The most noticeable difference between treatments was the large number of natural seedlings found on bulldozed lands. This superiority of bulldozed sites for natural regeneration is a fact of far-reaching economic importance to forest landowners now carrying out large planting programs.

Only one of all the stands in this study contained less than 700 seedlings per acre--both planted and natural--and one was below 50 percent milacres stocked. If 40 percent free-to-grow stocking is considered adequate, 31 out of 36 plantations were adequately stocked by a combination of naturally established and planted pine. The plantations which failed to reach 40 percent free-to-grow stocking were not confined to any single treatment.

Thus, within the range of total stocking encountered in this survey (averaging 68 percent, with none below 47 percent), the success or failure of plantations was dependent upon the control of competition. Although some of the competition was pine and yellow-poplar left to seed the plantations or to grow, an efficient cultural operation eliminating the overtopping cull hardwoods would bring the free-to-grow stocking in all plantations above 40 percent by milacres.

The average free-to-grow height, the height of the tallest 20 percent, and the average seedling height on dry and wet sites were analyzed in relation to site index and treatment, and failed to show any growth trend associated with these variables.

Field personnel observed that deep planting in relatively wet areas greatly reduced root development and height growth; also, honeysuckle on good sites reduced height growth of pine seedlings; and the windrowed area containing the shortest seedlings was flat, contained residual pond pine, and apparently had been puddled by heavy mechanical equipment.

Root Systems of Planted Pines

Over 2,000 root systems of planted seedlings were classified according to the form of the taproot. Compressed by bar planting, these root systems could readily be distinguished from the symetrical root systems of natural seedlings.

The typical good roots had a vertical taproot. The typical J-shaped root system had the tip of the taproot pointed towards the soil surface. The taproot in the L-root classification was pointed horizontally, and the balled roots had the taproot and laterals twisted together in an indistinguishable mass. Classes other than "good" included all kinds of twisted roots, and assignment to these classes was necessarily arbitrary. The most misshaped root system was the balled class, the J was less misshaped, and the L-root system resembled somewhat the drag-root system resulting from machine planting. Only 33 percent of the roots had good form (table 2 and figure 3).

The percentage of deformities in root systems was not related to treatment or planting organization. It appeared that the deformed root systems were a result of faulty planting technique, which was not restricted to any area, treatment, or organization.

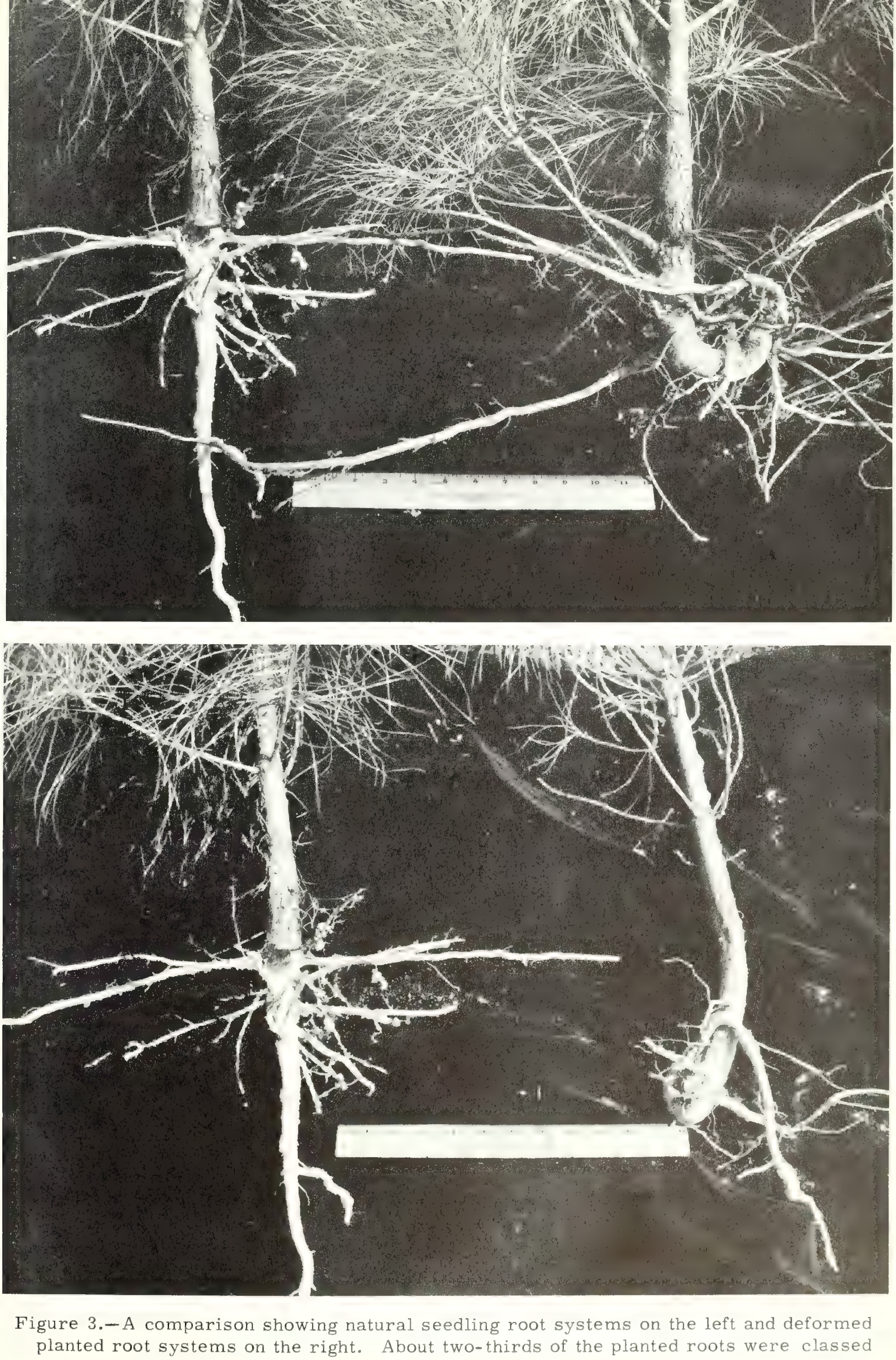

Figure 3.—A comparison showing natural seedling root systems on the left and deformed planted root systems on the right. About two-thirds of the planted roots were classed as deformed or misshapen.

Table 2.—Form of taproot (percent of total)

Treatment	Taproot classification			
	Good	L	J	Balled
	- - - - - - Percent - - - - - -			
No treatment	35	10	35	20
Disked	32	10	34	24
Bulldozed	30	13	37	20
Weighted average	33	11	35	21

Also, many seedlings were planted deep. Deep planting restricts root development on wet or imperfectly drained soils and hinders normal growth. Many deep-planted seedlings encountered in the survey on wet sites were short and had little chance in competition with native vegetation. The effect of deep planting should be evident at an early age, as the plant either grows well or falls behind and dies.

A poorly arranged root system is likely to have a longer-lasting influence on growth and survival than does depth of planting. Although there was little opportunity in this survey to determine early mortality, an occasional upturned seedling was noted, and in each such case the root system was balled and had no lateral root support on one or more sides. There is, of course, danger that other seedlings will upturn because of inadequate support. Observations elsewhere have shown that root systems of planted yellow pines can be attacked by Fomes annosus following thinning operations. It would thus seem advisable to try for normal root arrangement to lessen the danger of both overturn and infection. There is a real need for additional research on both the short- and long-term effect of depth of planting and root arrangement as related to site.

It is suspected that planting procedures were similar for each company, as the planting depth and percent of misshapen roots were about the same for each. It is also suspected that planters failed to follow the complete step-by-step operations recommended for bar planting. 6/

A failure to shake the seedling and to straighten roots by raising the root collar to the soil surface should not decrease first-year survival, and on droughty sites the resulting deep planting may increase survival. For this reason, improper depth of setting and failure to adjust roots by shaking is not apparent until the plant is lifted.

The necessity for training and supervising planting crews is stressed in planting literature. With the presently expanded planting programs, many temporary company and contract crews are operating during the relatively short planting season. It is sound economics to spend whatever is necessary to insure that the seedlings are firmly set to avoid mortality from drought, that the seedlings are planted to the depth desired, and that the root systems are placed in a somewhat normal arrangement. To provide adequate supervision, the foreman or forester in charge must have definite planting specifications, and he must repeatedly check each individual planter for compliance. It is not unreasonable to expect the foreman to check for firmness of planting, planting depth, and root arrangement of the trees planted under his supervision.

6/ Wakeley, P. C. Planting the southern pines. U. S. Dept. Agr. Monog. 18, 233 pp., illus. 1954.

DISCUSSION

Planting Was Often Unnecessary

It was impossible to determine survival percent under conditions of this study, since individual seedlings were not staked out at the time of planting.

Survival of planted pines and their growth into position estimated as free-to-grow was apparently not related to preplanting treatments. What preplanting treatments did was to reduce competition and create conditions that favor natural regeneration. When competition was measured for each treatment independently, the major effect of treatment was to influence the number of natural seedlings that became established. The planted areas examined were all on forest land, and regeneration of one sort or another began when stands were destroyed by logging, hardwood control, or mechanical treatment. Hardwood root stock sprouted, and hardwood and pine seedlings became established. Under these conditions the planting operation must be evaluated by its effect on improvement of free-to-grow stocking.

Table 3.— Free-to-grow stocking of natural loblolly pine, free-to-grow stocking added by planting, and total free-to-grow stocking under various treatments

Treatment	Stocking of natural seedlings	Stocking added by planting	Total stocking
	Percent		
No treatment	19	28	47
Disk	31	28	59
Bulldoze	45	18	63
Average	32	25	56

Planting did not improve the spacing of trees; and only on some windrowed, bulldozed plots was planted reproduction noticeably taller than natural reproduction. Planting did, on each plot, increase the free-to-grow stocking (table 3). At one extreme, a natural stand of 19 percent free-to-grow stocking was increased to 76 percent by planting; at the other extreme, the natural stand was 69 percent free-to-grow stocked, and planting increased the total free-to-grow stocking to 77 percent.

Oddly enough, the mechanical treatments to prepare the land for planting, by creating conditions favorable to natural reproduction, made planting less necessary.

Dollars and Cents

These data can be used in economic analyses. As an illustration: if planting costs \$10.00, mechanical treatments \$10.00, and hardwood control \$5.00 per acre, then (a) planting and poisoning treatment costs \$15.00; (b) bulldozing and planting \$20.00; and (c) disking, planting, and poisoning \$25.00. Using the increased stocking resulting from planting, there were 280 free-to-grow planted trees on nontreated and on disked areas, and 180 free-to-grow planted pines per acre on the bulldozed lands. The cost of each free-to-grow planted seedling thus becomes: (a) 5.4 cents, (b) 11.1 cents, and (c) 8.9 cents.

Another economic consideration might be the influence of disking and bulldozing on milacre establishment of free-to-grow naturals and planted pine. According to table 3, there were 470 free-to-grow pines per acre with no ground preparation. Following disking there were 590 per acre, and following bulldozing 630. It might be concluded that disking alone increased free-to-grow stocking by 120 seedlings per acre, and bulldozing by 160 per acre. If $10.00 is accepted as a cost for ground preparation, then seedlings added by disking cost 8.3 cents apiece, and each seedling added by bulldozing cost 6.2 cents.

The advisibility of removing competition can be approximated from figure 4 if poisoning costs are known. About 6 percent increase in free-to-grow stocking should result for the reduction of each 10 square feet of basal area of competition. On at least three plantations where the stand was not cut, the planted pine would have been entirely suppressed without a hardwood control job. The reduction of established competition is essential for both natural and planted seedlings.

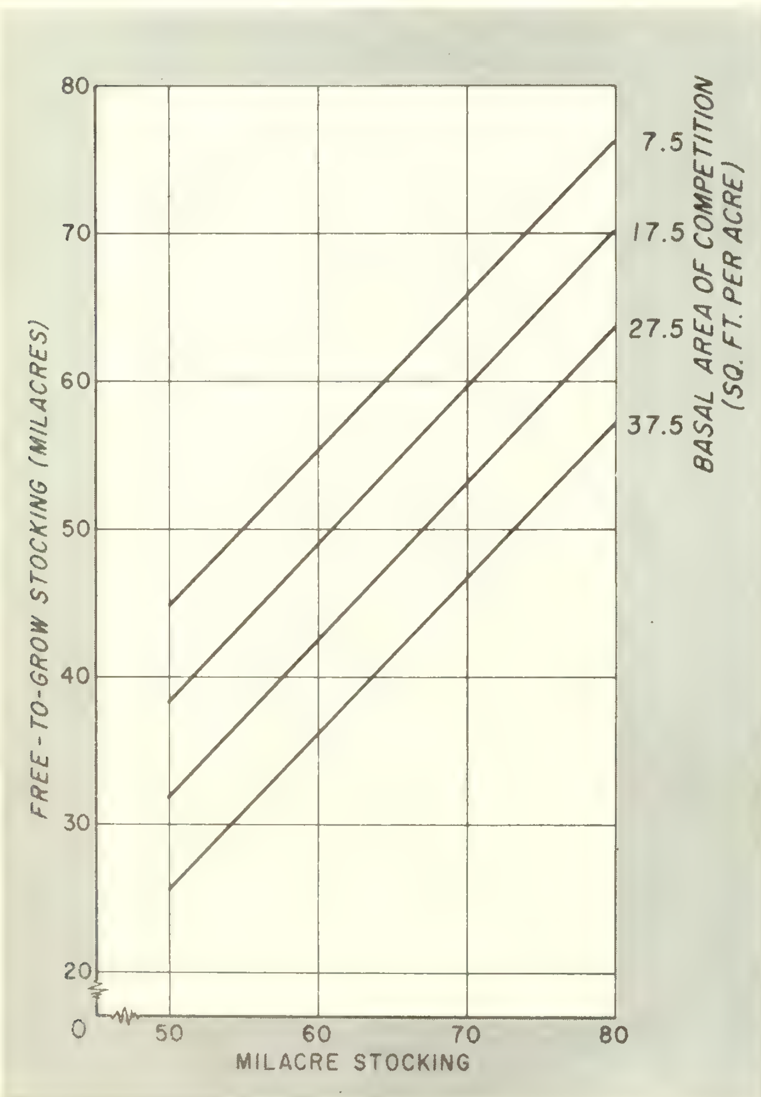

Figure 4.—Free-to-grow stocking related to total stocking and competition.

SUMMARY

Loblolly pine plantations made on recently harvested forest lands in 1954-1955 were studied following each of three preplanting methods: disking, bulldozing, and no treatment. The number of both planted and natural pines after three years in the field was determined, as well as the percent milacre stocking. Height and class of root system for planted pines were recorded.

Reproduction on each plot consisted of planted pines, natural pines, and hardwood sprouts and seedlings. Larger competition of both pine and hardwood trees overtopping reproduction was the least on bulldozed lands and the most on lands that had no ground preparation. The reduction of established competition is essential for both natural and planted seedlings.

Examination of existing coastal plain loblolly pine plantations tends to be misleading because obstructions such as stumps and windrows make the spacing irregular, and wildings, which can scarcely be distinguished from planted seedlings may comprise a majority of the stand.

Three years after planting, there were 579 planted pines per average acre, and these produced stands 51 percent stocked by milacres. However, 14 of the 36 plantations contained over 1,000 natural seedlings per acre and, on the average, there were more natural than planted seedlings. More natural seedlings occurred on bulldozed than on either disked or nontreated areas. On the basis of planted pines solely, half the plots would be considered failures if 40 percent free-to-grow is the lowest stocking acceptable.

The combined pine reproduction averaged 1,445 seedlings per acre, 68 percent stocked, and 56 percent stocked free-to-grow. All the plots could be raised to 40 percent stocked free-to-grow by treatments designed to reduce competition. On bulldozed lands, the seedlings that came in naturally stocked 53 percent of the plots adequately. The most noticeable difference between treatments was the large number of natural seedlings found on bulldozed lands.

This study confirms many research reports on natural regeneration of loblolly pine following harvest in the coastal plain; as those reports pointed out, loblolly pine regenerates naturally provided seed trees are adequate, harvest takes place in a moderately good seed year, soil is scarified, and hardwoods are controlled. The additional stocking occasioned by planting is indeed costly in terms of increased stocking. Assuming hardwood control for all but the bulldozed treatments, each additional free-to-grow planted seedling cost 5.4 cents with no ground preparation, 8.9 cents with disking, and 11.1 cents with bulldozing. Two-thirds of these expensive seedlings had misshapen root systems which could handicap future growth.

Silvical Characteristics of Winged Elm

by

Robert D. Shipman

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U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Southeastern Forest Experiment Station
Asheville, North Carolina

Silvical Characteristics of Winged Elm

(*Ulmus alata* Michx.)

by

Robert D. Shipman[1/]

A single species of winged elm (*Ulmus alata* Michx.) is recognized (5). Other common names are wahoo, hard elm, rock elm, and white elm. It is found principally in southeastern United States, ranging westward from the borders of swamps and streams in southeastern Virginia, southwestern Indiana, southern Illinois (Richland and Johnson counties) to southern Missouri (fig. 1). Southward it is found in central Florida (Lake County) and the valley of the Guadalupe River, Texas, and as far west as Garfield County in Oklahoma (9).

HABITAT CONDITIONS

CLIMATIC

The distribution of winged elm is principally within the humid climatic province of the southeastern United States, according to Thornthwaite's classification (12). Annual precipitation within its growing area averages 45 to 60 inches as recorded for the period 1899-1938. One-half or more of this precipitation falls within the warm months--April to September. Throughout the main part of the tree's commercial range, the growing season averages from 180 to 300 days, and average annual temperature from 55° to 70° F. Average annual snowfall varies from 0 inches in the extreme southern range to 15 inches in the north, and the number of days with snow cover ranges from 0 days in the south to 20 days in the north (13).

EDAPHIC AND PHYSIOGRAPHIC

The soil requirements of winged elm are much the same as for American elm. As evidenced by its range, the species can be found on a great variety of soils occurring in southeastern United States. Winged elm grows fairly well on dry as well as on rich, moist soils (14). Its best development is principally on loamy flats (as in the Mississippi River Delta). On the latter bottomlands it occurs widely on terrace ridges and colluvial sites. Occasionally it is found

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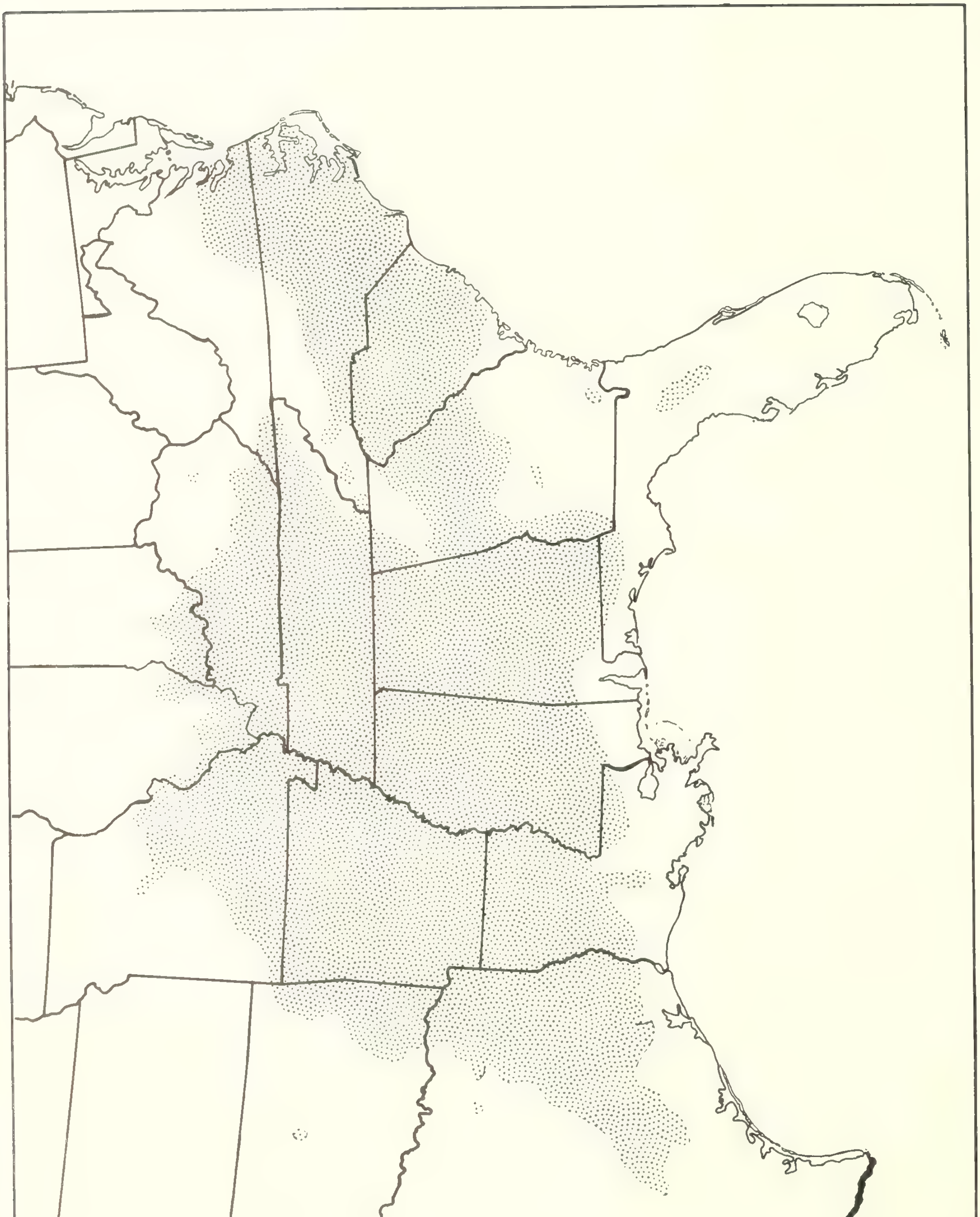

Figure 1.--Botanical range of winged elm.

on high terrace flats with tight silty soils (7). Normally, winged elm is never associated with standing water except in the form of intermittent pools and shallow sheets after heavy winter rains (8). In southern Illinois, it occurs in old abandoned fields and along fence rows on upland clay soils. The species is generally associated with intermittent streams and other moist lower-slope sites. However, in the hill country of Tennessee and North Carolina, it may be found on upper or middle slopes.

BIOTIC

Winged elm generally occurs only as scattered trees in mixture with other hardwoods. It is not a major component of any forest cover type in eastern United States, but is found in varying amounts in five major cover types. In the Central States it occurs as a minor species in the post oak-black oak type. From the Central States southward through Tennessee, Arkansas, Mississippi, and Alabama it is associated with the eastern redcedar-hardwood type or in the white oak-red oak-hickory cover type. In the Southern Forest Region and within flood plains of major rivers, winged elm is found in either the swamp chestnut oak-cherrybark oak type or in the sugarberry-American elm-green ash association (10).

Tree species associated with winged elm vary by locality and site. In bottomland or flood plain areas, the chief associates are swamp chestnut oak (*Quercus michauxii*), cherrybark oak (*Quercus falcata* var. *pagodaefolia*), American elm (*Ulmus americana*), green ash (*Fraxinus pennsylvanica*), willow oak (*Quercus phellos*), blackgum (*Nyssa sylvatica*), hickories (*Carya* spp.), red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), southern red oak (*Quercus falcata*), yellow-poplar (*Liriodendron tulipifera*), and American beech (*Fagus grandifolia*). It is also found in the loblolly-hardwood type (8).

In the Southern Forest Region, common weed tree associates are eastern hophornbeam (*Ostrya virginiana*), American hornbeam (*Carpinus caroliniana*), and sassafras (*Sassafras albidum*). In Arkansas, holly (*Ilex opaca*) is a common weed tree associate.

LIFE HISTORY

SEEDING HABITS

Flowering and fruiting.--The perfect flowers are vernal, appearing before the leaf buds unfold. They are borne on drooping pedicels in short, few-flowered fascicles. The fruit is a samara, ripening before or with the unfolding of the leaves, one-third inch in length and tipped at the apex with long incurved awns and covered with long white hairs (9). Very little is known about the effects of climatic factors on the flowering and fruiting of winged elm. Little or nothing is known of the effects of animals, birds, insects, and diseases on the flowering and fruiting of this species. Four species of game birds are known to consume elm seed. These are the ruffed grouse (*Bonasa umbellus*), bobwhite (*Colinus virginianus*), Hungarian partridge (*Perdix perdix perdix*), and pinnated grouse (*Tympanuchus cupido*). Elm seed

have been taken from the stomachs of the opossum (Didelphis virginiana virginiana), cottontail rabbit (Sylvilagus floridanus), and snowshoe hare (Lepus americanus). It is reported to be heavily browsed by the white-tailed deer (Odocoileus virginianus) (16).

Winged elm is not a tree of primary importance; hence knowledge concerning seed production and vegetative propagation is meager.

SEEDLING DEVELOPMENT

The specific requirements for the germination and survival of winged elm seedlings have not been studied, so little can be said concerning seedling establishment. A study recently conducted at the University of Missouri shows that winged elm seedling development is best at one-half sunlight intensity. One-half light intensity resulted in the greatest height growth of winged elm, while best growth for American elm was at one-third light intensity. From this test, winged elm was found to be a light-demanding species when associated with American elm and red maple (6). In flood-plain areas of the Delta Region, reproduction is prolific in openings but very sparse as an understory (8).

SAPLING STAGE TO MATURITY

The winged elm is medium in size, usually from 40 to 50 feet in height, occasionally 80 to 100 feet, developing a short bole, 1 to $1\frac{1}{2}$ feet in diameter, with branches ascending into a fairly open, round-topped crown (fig. 2). It has a lacy, or somewhat drooping, habit. One special characteristic is the corky, persistent wings, or projections, often found on the branchlets (4). In the absence of natural stands of commercial importance, volume and yield values are not available. Winged elm in open shade-tree conditions grows rapidly but many of its hardwood associates will exceed the diameter growth of the species in the open. Under forest conditions its growth rate is usually considered poor in relation to its associates (7).

The principal use of winged elm is in standard hardwood lumber which is usually mixed with American elm and handled by the trade as soft elm (4). Other minor uses are for boxes, baskets, crates, and barrels. Occasionally it is used for furniture, caskets, ties, pallets, and vehicle parts. The wood is heavy, hard, and close-grained, and it is difficult to split. The wood of winged elm does not possess great strength (9).

Two of the most important diseases attacking winged elm are the Dutch elm disease (Ceratostomella ulmi) and phloem necrosis virus (1). These diseases are still primarily a problem in shade trees and as yet not serious in forest stands. The species is subject to top dieback of varying degree, the cause of which has been undetermined.

Figure 2.--A typical open-grown winged elm standing on the School Forest of Clemson College, Clemson, S. C.

As with American elm, this tree is attacked by a long list of insect defoliators, bark beetles, borers, and sucking insects, but the damage is largely confined to shade trees (3, 15). The smaller European elm bark beetle (*Scolytus multistriatus*) and the elm leaf hopper (*Scaphoideus luteolus*) are important as vectors of the Dutch elm disease and elm phloem necrosis, respectively (11). The red-shouldered hickory borer (*Xylobiops basilaris*) damages the wood of dying trees and green logs of winged elm (2).

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Agriculture - Asheville

Site Index Comparisons for Several Tree Species in the Virginia-Carolina Piedmont

by

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INTRODUCTION

The Piedmont of southern Virginia and the Carolinas contains thousands of acres of pine-hardwood forests. The most widespread commercial timber type of the region is the shortleaf pine-hardwood type. The less extensive Virginia pine-hardwood type lies along the western edge of the Piedmont, but reaches its peak development in the adjacent Appalachian Mountain region (fig. 1). The natural forest succession in the Piedmont proceeds from pure pine to mixed pine-hardwood to nearly pure stands of the more tolerant hardwoods (6), and hardwood species gradually crowd out pine and dominate the mixed forests. The tendency of hardwoods to encroach on pine is helped out by man through heavier cutting of pine than of hardwood, and by efficient and widespread forest fire protection.

Forest managers in the Piedmont (primarily farmers with small woodland holdings) are faced with the problem of profitably managing stands of timber with a gradually increasing hardwood component. This job is formidable because hardwoods generally do not have wood properties desirable in mass-demand products, such as house framing and kraft paper. These multiplying hardwoods, added to an already over-abundant supply of low-grade trees throughout the eastern United States, constitute a major problem in forest management and utilization.

There are a variety of marketing outlets in the Piedmont for both pine and hardwood species. The presence of these diversified markets creates an immediate need for knowledge about the relative productivity of forest land for different tree species. Unlike many parts of the South, where pine completely dominates the marketplace, the Virginia-Carolina Piedmont challenges the forest manager to choose whether he will grow various oaks, yellow-poplar, pine, or mixtures of these with other special-use species, such as walnut and ash.

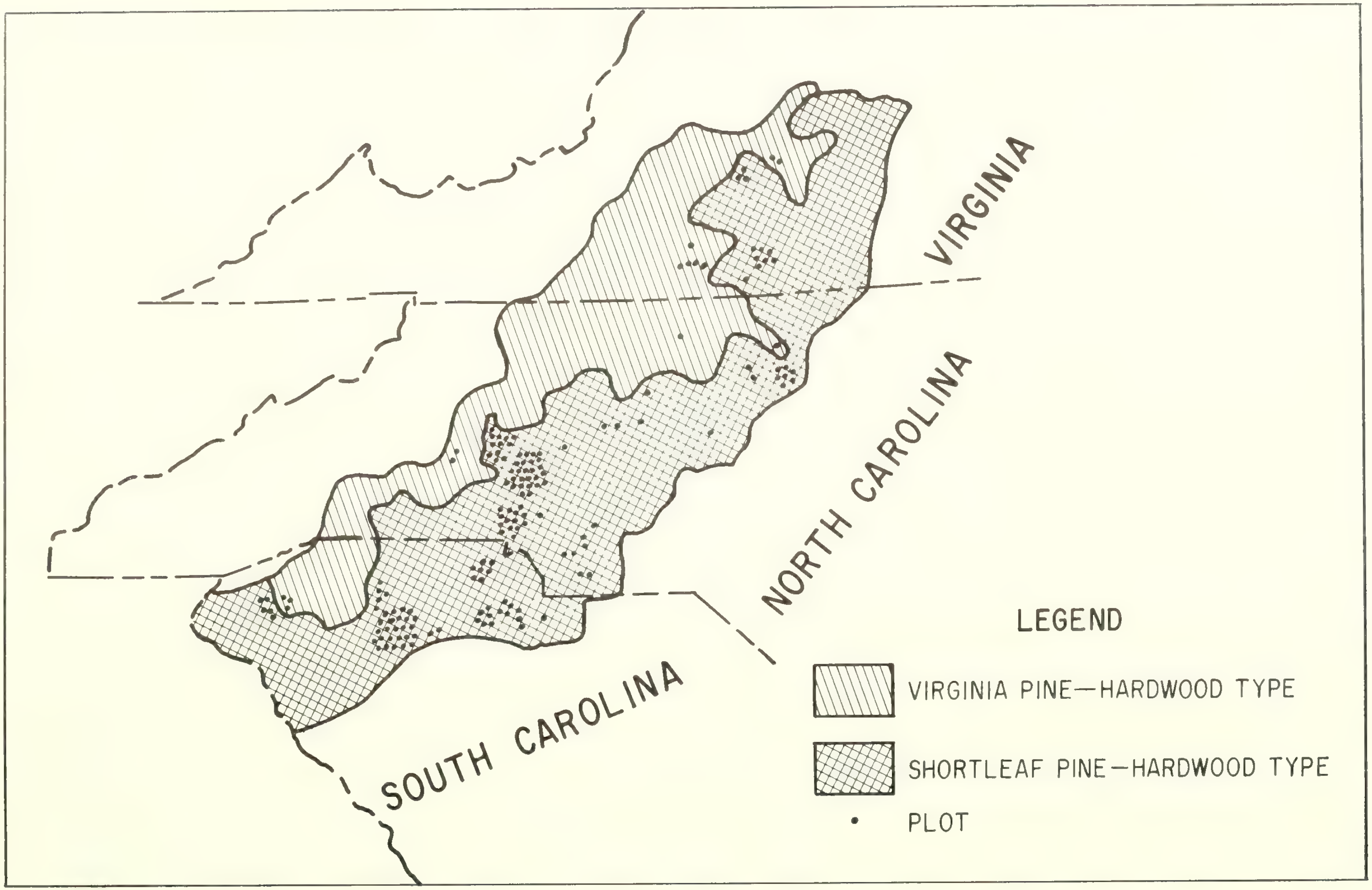

Figure 1.--Plot location map for the site index comparison study in the Virginia-Carolina Piedmont region.

This study compares the site index of several commercial timber species growing on comparable soils. It is a step toward determining relative productivity, and when added to knowledge about timber quality, yield per acre, and marketability, will aid landowners in deciding what kind of forests to grow.

These site index comparisons have been developed as one part of a larger effort to determine the site indices of several species in relation to permanent features of the soil and physiography. The comprehensive soil-site work will be published in the future, based on the identical tree data used in this study. Relating the site indices of several species to one another will furnish estimates of site index for a large number of species conveniently and quickly, if site index for one species can be determined by conventional means.

FIELD METHODS

Plots from 1/5 to 1/2 acre in size were established in 155 upland Virginia-Carolina Piedmont forest stands. Study areas were located so that the plot would be homogeneous with respect to soil type, topography, aspect, and degree of slope. Only second-growth stands older than 20 years were sampled; stands older than 120 years were avoided. The location of plots was confined to the shortleaf pine-hardwood and Virginia pine-hardwood types. On each plot an aggregate of four dominant and codominant trees of as many species as possible were selected and numbered. Some plots had as many as seven species and others only two. Four or five species on a plot was the most common occurrence. The tree species measured were: Yellow-poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), southern red oak (*Q. falcata* Michx.), northern red oak (*Q. rubra* L.), sweetgum (*Liquidambar styraciflua* L.), shortleaf pine (*Pinus echinata* Mill.), Virginia pine (*P. virginiana* Mill.), loblolly pine (*P. taeda* L.), and eastern white pine (*P. strobus* L.). Each plot was selected to contain yellow-poplar, white oak, or shortleaf pine, as index species with which to compare all others.

For each selected tree the total height, age, and diameter breast high was determined. Four years were added to the age from a boring at breast height to determine total age for all species except yellow-poplar and sweetgum. Three years were added to yellow-poplar breast high age, and nothing was added to sweetgum because the site curves were based on breast high age.

Ages and heights for the four trees of each species were averaged, and a single site index value was obtained for each species. These were then grouped in a plot-by-plot tally so that prediction equations could be computed.

ANALYSIS OF DATA

General

The field tabulations were sorted to see if data on all eleven species could be used. Since loblolly and eastern white pine were found on less than ten plots, they were not considered in further analysis of the data. Insufficient data were tabulated for sweetgum and Virginia pine to make strong comparisons of site index with other species, but the mean and range of site indices encountered for these two species are included (table 1), and their position in upland Piedmont forests is discussed later. As a result of these limitations, the seven major species retained for comparative analysis were the four in the red oak group, white oak, yellow-poplar, and shortleaf pine.

Table 1.--Site index of important Piedmont species: Mean, range, and associated species

Species	Code number	Plots	Mean site index	Highest site index	Lowest site index	Associated species: Plot with highest site index	Associated species: Plot with lowest site index
		Number	Feet	Feet	Feet	Code Number	Code Number
Yellow-poplar	1	97	83	122	55	2,9	5,7,8
White oak	2	99	69	90	49	1,9	3
Black oak	3	59	73	98	50	1,4,7	2
Scarlet oak	4	55	76	96	56	1,2,3,6,7	1,2,3,7
Southern red oak	5	36	69	88	52	1,2,3,4,6	1,8
Northern red oak	6	23	83	102	72	1,4	1,2,7,8
Shortleaf pine	7	103	64	88	44	1,6,9	2
Virginia pine	8	28	72	93	57	7	2,3,4,5,7
Sweetgum	9	12	90	112	69	1	1,7

Site Classification

Classification of site index at age 50 for oak, yellow-poplar, and shortleaf pine growing in mixed stands on the Piedmont presented certain difficulties. Oak curves developed by Schnur (7), yellow-poplar by McCarthy (3), and shortleaf pine from USDA Miscellaneous Publication 50 (9) and Coile and Schumacher (1) were not entirely applicable. The study plots were located in mixed stands, whereas data for existing curves came from nearly pure stands. Also, the geographic range of the data for existing oak and yellow-poplar curves did not include the Piedmont region.

Site classification for this study was based on equations of the form, Logarithm of Total Height = a + b $\frac{1}{(\text{Total age})}$, using the height and age data obtained on the comparative site index plots. For oak, the basic relationship was identical for oak in the Piedmont and Southern Appalachian mountains (5). The equations for derivation of a family of site index curves are as follows:

(1) Oak. Because statistical tests showed no significant difference in the rate of height growth relationship by species and no differences between Piedmont and mountain oaks, a single equation is sufficient for all oak species under study.

$$\text{Log H} = 2.028 - 9.5639\left(\frac{1}{A}\right)$$, based on 697 observations, i.e., plots.

(2) Yellow-poplar

$$\text{Log H} = 2.046 - 6.5788\left(\frac{1}{A}\right)$$, based on 98 observations.

(3) Shortleaf pine

$$\text{Log H} = 2.027 - 10.9081\left(\frac{1}{A}\right)$$, based on 103 observations.

The major species were classified according to these three equations. Site index for sweetgum was determined from Winters and Osborne (10), and for Virginia pine from Slocum and Miller (8). Site index was recorded to the nearest foot.

Comparative Site Index

All possible paired species combinations were analyzed to determine regression equations which would define in general terms the relationship in site index between species. The analysis revealed that the only reliable independent variable (index species) to use in formulating prediction equations was yellow-poplar. It was also discovered that white and southern red oak and scarlet and northern red oak could be grouped for analysis. Neither shortleaf pine nor white oak was entirely satisfactory as an index species because of the limited range of site index values encountered (table 1). Yellow-poplar, on the other hand, exhibited a range from near the lowest shortleaf pine and white oak value to over 30 feet greater than the highest of these two species. This shows that yellow-poplar is highly sensitive to the various site factors found on the Virginia-Carolina Piedmont, and this fact can be put to use predicting site index for numerous other species. Doolittle (2) discovered a similar relationship in the Southern Appalachians.

A tabulation of the regression equations using yellow-poplar as the independent variable (x) is made in table 2. Statistical tests revealed no significant differences between slope of the comparative regressions. They differed only in level and are parallel. Figure 2 presents the equations in a chart for easy use. This graphic comparison and the equations must be used with caution, because both the x and y terms contain experimental error. The presence of experimental error in site index curves and the comparative equations is under further study. Results of this work will be released later. Nevertheless, the

curves do indicate valid trends, and make it possible to estimate the site index of any of the seven major species if the site index of yellow-poplar can be determined by conventional means.

Table 2.--Comparison equations using yellow-poplar as the index species

Species comparison	Comparisons	Regression equation[1/]	Level of significance
	Number		Percent
Yellow-poplar Shortleaf pine	62	$Y_{slp} = 31.5 + 0.45x_{yp}$	1
Yellow-poplar White-Southern red oak	67	$Y_{wo} = 36.7 + 0.45x_{yp}$	1
Yellow-poplar Black oak	42	$Y_{bo} = 39.7 + 0.45x_{yp}$	1
Yellow-poplar Scarlet-Northern red oak	44	$Y_{so} = 44.5 + 0.45x_{yp}$	1

1/ Y_{slp} denotes site index of shortleaf pine; Y_{wo}, white and southern red oak; Y_{bo}, black oak; Y_{so}, scarlet and northern red oak. X_{yp} denotes site index of yellow-poplar.

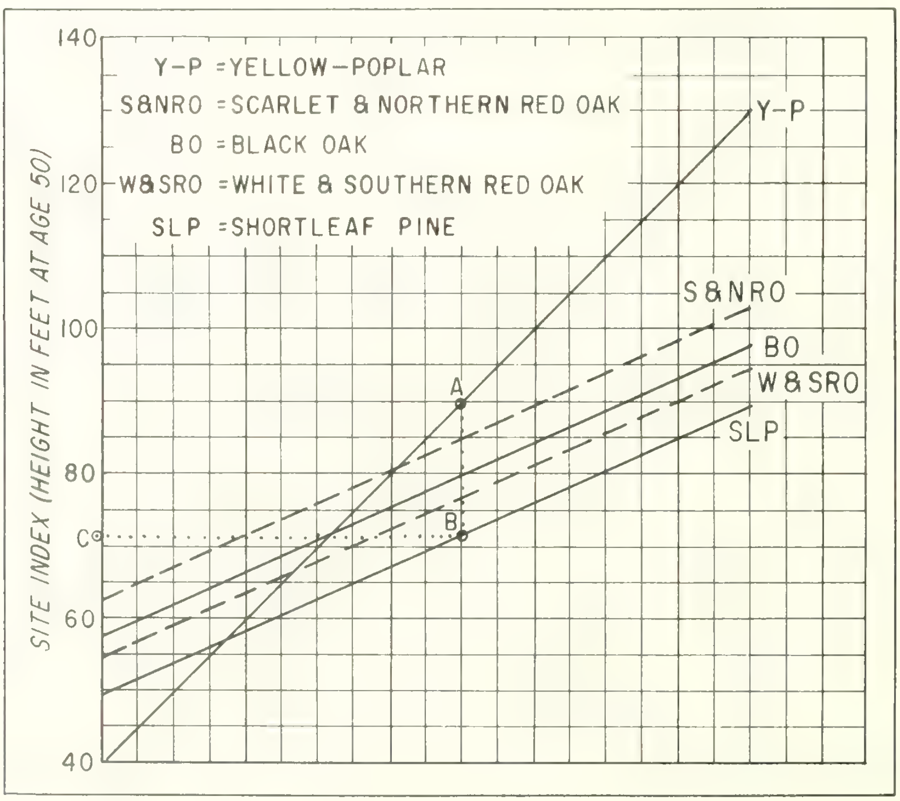

Figure 2.--A site index comparison study for important timber species in the Virginia-Carolina Piedmont. For example, on land that is site index 90 (A), for yellow-poplar, read down (B) and across (C) to find that this same land averages about 72 feet for shortleaf pine.

RESULTS AND DISCUSSION

The comparisons among species reveal that for yellow-poplar site index of 81 feet or more, yellow-poplar has the highest site index value of any Piedmont species. However, data on the few plots on which sweetgum occurred with yellow-poplar indicate that sweetgum has a site index about equal to yellow-poplar where the two grow together on upland, residual soils. Associations of yellow-poplar and sweetgum on upland sites in the northern Piedmont are infrequent. Nelson and Beaufait (4) report that yellow-poplar and sweetgum on the Georgia Piedmont can be grouped as a single independent variable for formulating prediction equations in that region, but their field plots included many bottomland sites.

When the yellow-poplar site index falls below 81 feet, down toward the minimum, scarlet and northern red oak, black oak, white and southern red oak, and finally, shortleaf pine exceed yellow-poplar in site productivity based on height at age 50. For yellow-poplar site index of 57 feet and below, yellow-poplar has the lowest site index of any Piedmont species.

Virginia pine is the one major species of the northern Piedmont upland forests which cannot be directly compared in this study using yellow-poplar as an index. The two occurred together on only 13 plots, and no satisfactory prediction equation could be formulated from so few observations. Virginia pine was present on a total of only 28 out of 155 established plots (table 1). This reflects a marked tendency on the part of Virginia pine to occur in pure stands, and the species can be found on many of the shallowest soils and drier, exposed situations in the Piedmont. Examination of the available data indicates that Virginia pine exceeds white oak in site index throughout the range covered in figure 2, and would be intermediate in site index between the white and black oaks. Virginia pine consistently has a higher site index than shortleaf pine when the two are associated.

In general, the findings of Doolittle (2) in the Southern Appalachians, and of Nelson and Beaufait (4) in the Georgia Piedmont agree closely with the results of this study regarding species which are common to the three regions. Yellow-poplar exceeds all oak species and shortleaf pine for above-average sites and gets progressively poorer in relation to the other species on the low index sites. In this study, shortleaf pine is lower than all other associated species except on the very poor sites, while in the Southern Appalachians, white oak, shortleaf, and pitch pine share the lowest relative position.

SUMMARY

Total height and total age were obtained for dominant and codominant trees of as many species as possible in 155 upland, northern Piedmont forest stands. From two to seven species were found associated on each of the plots. Site index equations were developed for oak, yellow-poplar, and shortleaf pine growing in these mixed forests of the Virginia-Carolina Piedmont. The site index of other species was determined with the use of published curves.

The site indices of all species were compared, and yellow-poplar was the only widely occurring species with a sufficient range of site index to serve as an index species. Using yellow-poplar as the independent variable, equations were computed for estimating the site index of scarlet and northern red oak, black oak, white and southern red oak, and shortleaf pine. These were presented in chart form (fig. 2) and make it possible to estimate the site index of any of these seven major species if the site index of yellow-poplar can be determined by conventional means.

Though direct comparisons with yellow-poplar could not be made for sweetgum and Virginia pine, the role of these two species in upland, northern Piedmont forests is discussed.

The most significant results of these site index comparisons are: (1) yellow-poplar exceeds all other Piedmont species in site index on sites which are 81 feet or more for poplar; (2) as the site index for yellow-poplar falls below 81 feet, the oaks, shortleaf, and Virginia pine begin to exceed yellow-poplar in site productivity, and yellow-poplar becomes the poorest of the seven species at site index 57 and under; and (3) throughout the range of yellow-poplar site index from 58 to 130 feet, shortleaf pine has a lower indicated site index than any of the commonly associated Piedmont species.

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Silvical Characteristics of Mockernut Hickory

by

Thomas C. Nelson

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November 1959

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Southeastern Forest Experiment Station
Asheville, North Carolina

Silvical Characteristics of Mockernut Hickory

(Carya tomentosa Nutt.)

by

Thomas C. Nelson
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Mockernut hickory (Carya tomentosa Nutt.), characteristically a southern species, is one of the commercially important true hickory species (16). This species is also referred to locally as bullnut, white hickory, white heart hickory, and hognut, although it loses its species name in the lumber trade and is marketed as "hickory" (8). "Big bud" is another local designation (2).

Although mockernut is distributed from southern Ontario southward (9), it is not common north of southeastern Pennsylvania and New Jersey. It becomes more abundant southward through Virginia, North Carolina, and Florida where it is the commonest of the hickories and furnishes the bulk of the hickory cut. This species is abundant in the lower Mississippi Valley and reaches its largest size in the basin of the lower Ohio River and in Missouri and Arkansas. Mockernut is the only hickory found in the pine forests of the sandy maritime pine belt of the Southern states (9). In the northern part of its range, it is mainly confined to the coastal region (6). The general range is shown in figure 1.

Mockernut hickory is used for tool handles requiring high shock resistance (fig. 2). It is also used for ladder rungs, athletic goods, agricultural implements, dowels, gymnasium apparatus, poles, shafts, well pumps, and furniture. Lower grade lumber is useful for pallets, blocking, and similar items (16).

HABITAT CONDITIONS

CLIMATIC

Mockernut hickory grows in a climate generally classified as humid by Thornthwaite (13). Mean annual precipitation ranges from 30 to 60 inches within the range of the species. Twenty to 30 inches of rain falls during the growing season. Forty inches of snowfall per year is not uncommon in the northern portion of the range, but snowfall is a rarity at the southern extreme (7).

Average annual temperatures range from 45° to 70° F.; average July temperatures from 70° to 80°; and average January temperatures from 20° to 55°. Extremes of 115° and -40° have been recorded within its range. The growing season is as short as 120 days in the northern portion of the range and as long as 320 days in the southern portion (7).

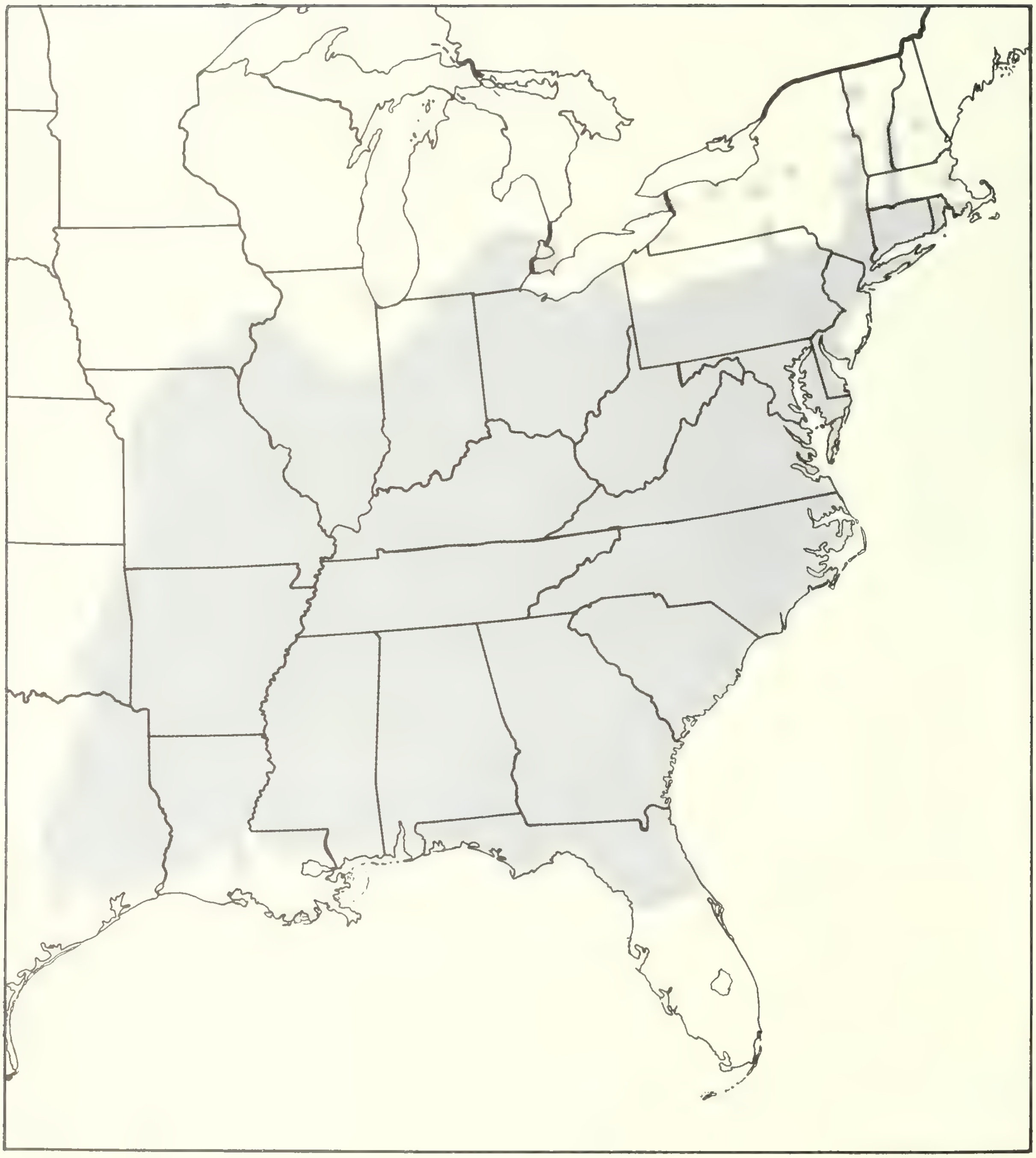

Figure 1.--Botanical range of mockernut hickory.

Figure 2.--Mockernut bolts at hickory mill near Macon, Georgia.

EDAPHIC AND PHYSIOGRAPHIC

As is characteristic of many hickory species, the preferred site for mockernut hickory varies within its range. In the north, it grows on the better ridge and hillside soils and, less frequently, on the alluvial bottoms (19). In the Cumberland Mountains and the hills of southern Indiana, mockernut grows in dry situations, such as south and west slopes or dry ridges. Stunted mockernut grows in Alabama and Mississippi upon the sandy shortleaf and loblolly pine land. The species is also found as a dwarf in company with yaupon (Ilex vomitoria) and live oak (Quercus virginiana) along the sand dunes of South Carolina (5); here the dwarfing is probably due to environmental conditions. However, most of the merchantable mockernut grows on moderately fertile uplands, and attains its best development only on fresh, deep fertile soil (2).

BIOTIC

Mockernut hickory is usually found as a component of the eastern oak-hickory forest although it also occurs in beech-maple forests (fig. 3). It is a major component of the northern red oak-mockernut hickory-sweetgum type and an associate of four other forest types (11).

Figure 3.--A forest-grown mockernut hickory, located in the University of Georgia Watson Springs School Forest. The tree is 101 feet high and measures 22.5 inches d.b.h.

The common associates of mockernut hickory vary widely for selected locations throughout its range (table 1).

Table 1.--Associates of mockernut hickory in selected sections of its range

Region	Associated species	Authority
New England Coastal Plain	Oaks (Quercus spp.) Eastern redcedar (Juniperus virginiana) Sassafras (Sassafras albidum) Sweet birch (Betula lenta) Sweetgum (Liquidambar styraciflua) Yellow-poplar (Liriodendron tulipifera)	Hough (6)
Cumberland Plateau	White oak (Quercus alba) Black oak (Quercus velutina) Post oak (Quercus stellata) Shagbark hickory (Carya ovata) Yellow-poplar Flowering dogwood (Cornus florida) Shortleaf pine (Pinus echinata) Pitch pine (Pinus rigida)	Braun (3)
Piedmont Lowland	White oak Northern red oak (Quercus rubra) Black oak Shagbark hickory	Braun (3)
Piedmont Upland	Loblolly pine (Pinus taeda) Longleaf pine (Pinus palustris) Shortleaf pine Southern red oak (Quercus falcata) Post oak Black oak Pignut hickory (Carya glabra) Flowering dogwood	Braun (3)
Southern Bottomland Hardwood Region	Swamp chestnut oak (Quercus michauxii) White oak Delta post oak (Quercus stellata var. mississippiensis) Nuttall oak (Quercus nuttallii) Water oak (Quercus nigra) Sweetgum American elm (Ulmus americana) Green ash (Fraxinus pennsylvanica) White ash (Fraxinus americana) Winged elm (Ulmus alata) Black tupelo (Nyssa sylvatica)	Westveld (18)

LIFE HISTORY

SEEDING HABITS

Flowering and fruiting.--Like the other hickories, the flowers of mockernut hickory are borne in separate flowers on the same tree (monoecious). The male catkins are four or five inches in length, with slender stems and common peduncles coated with matted hairs. Female flowers are produced in crowded two- to five-flowered spikes (9).

Mockernut flowers open from early April in southern Florida to the end of May in eastern New England (9). Fruit ripens in September and October, and seed dispersal occurs from September through December (15) (fig. 4).

Seed production.-- Mockernut hickory requires a minimum of 25 years to reach commercial seed-bearing age. Optimum seed production occurs from 40 to 125 years, and the maximum age listed for commercial seed production is 200 years (15).

Good seed crops occur every 2 to 3 years with light seed crops borne in the intervening years (15). Approximately 50 to 75 percent of fresh seed will germinate (12). Hickory shuckworm (*Laspeyresia caryana*) is probably a major factor in reducing germination.

Mockernut hickory, although seldom cultivated for fruit production, produces sweet, tasty nuts which are edible by humans, and the fruit forms a portion of the diet of racoon (*Procyon lotor*), red squirrel (*Sciurus hudsonicus*), eastern gray squirrel (*Sciurus carolinensis*), eastern fox squirrel (*Sciurus niger*), and eastern chipmunk (*Tamias striatus*). The twigs and young stems of mockernut hickory are browsed by white-tailed deer (*Odocoileus virginianus*) (17).

Seed dissemination.--Mockernut is one of the heaviest seeded species of *Carya*, averaging 90 seed per pound (15). The seed is disseminated mainly through gravity and by various species of squirrels.

VEGETATIVE REPRODUCTION

There is ample evidence in the literature on the ability of the genus *Carya* to sprout prolifically (2). Although mockernut hickory is not specifically mentioned, casual observation indicates that it will sprout prolifically following fire and cutting.

SEEDLING DEVELOPMENT

Establishment.--Hickories, in general, require a moderately moist seed bed for satisfactory seed germination (18), and mockernut appears to reproduce best in moist duff.

Young mockernut hickories are very susceptible to frost. This factor has proved an obstacle to its introduction into Germany (2).

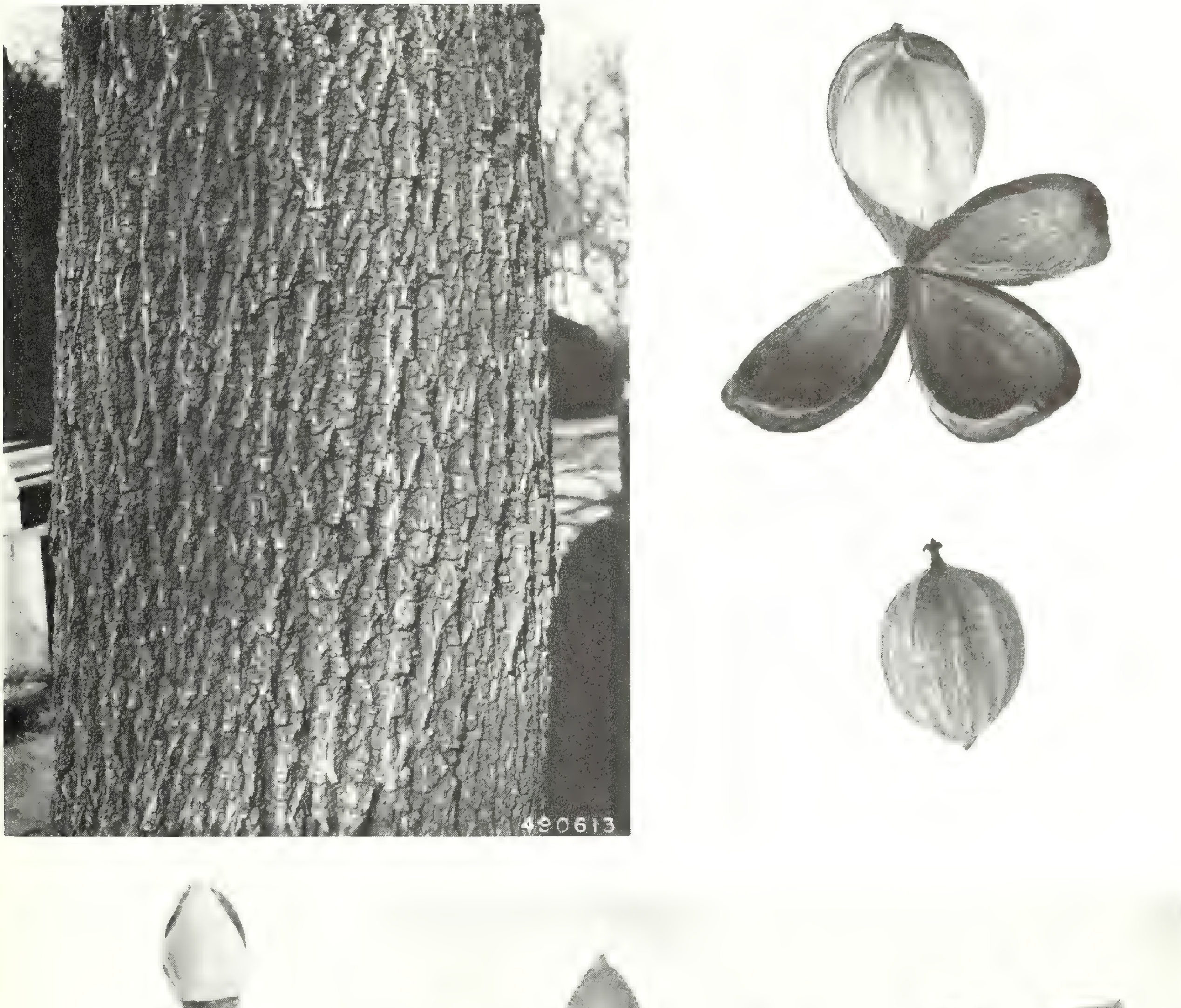

Figure 4.--Typical bark, fruit, twig and bud, and leaves of mockernut hickory.

Early growth.--Height growth of mockernut seedlings is slower than the growth of its associates. Boisen and Newlin (2) report the following height growth of seedlings in the Ohio Valley in the open or under light shade, on red clay soil:

Age (Years)	Height (Inches)
1	3.0
2	4.7
3	8.0
4	12.5
5	20.0
6	28.0

SAPLING STAGE TO MATURITY

Growth and yield.--Mockernut hickory seldom reaches 100 feet in height or 3 feet in diameter; it is usually much smaller (6, 7). Height growth in relation to age is shown in table 2.

Table 2.--Height growth of mockernut hickory in the Cumberland Mountains and Mississippi Valley (2)

Age (years)	Height	
	Cumberland Mountains	Mississippi Valley
	Feet	Feet
10	4	9
20	17	18
30	26	25
40	33	30
60	45	40
80	55	49
100	66	57
120	76	65
160	94	80
200	109	95

The current annual growth of mockernut hickory in dry situations is estimated at 15 cubic feet per acre per year. In fully stocked stands on soils of moderate fertility, 30 cubic feet per acre per year is a safe estimate, although growth rates of 44 cubic feet per acre per year are reported from Ohio (2).

Reaction to competition.--Mockernut hickory is classified as intolerant by Zon and Graves (19). However, Boisen and Newlin (2) state that a peculiar tolerance feature of the hickories is the remarkable rapidity with which they recover from suppression. It is probably a climax species on the moist sites upon which it occurs.

Principal enemies.--Mockernut hickory, like most hickories, is extremely susceptible to damage by woods fires (16).

It is host to several leaf and twig fungi, which cause little serious damage other than varying degrees of defoliation. Leaf blotch (*Mycosphaerella dendroides*), anthracnose (*Gnomonia caryae*), witches' broom (*Microstroma juglandis*), and scab

(Cladosporium effusum) are probably the most common. Phomopsis tumor is widespread on hickories and probably occurs on mockernuts (4). In common with most hardwoods, mockernut is susceptible to progressive heart rot caused by several fungi which often gain entrance into the tree through fire wounds.

A trunk rot caused by Poria spiculosa causes serious downgrading of hickory trees and logs. Nectria galligena, a bark canker, and Clitocybe parasitica, a root rot, have also been reported on mockernut hickory (14).

Although mockernut hickory is often and repeatedly subjected to serious damage by insects, there are relatively few insects which have been reported as specifically attacking mockernut. The hickory bark beetle (Scolytus quadrispinosus), the hickory spiral borer (Agrilus arcuatus var. torquatus), and the pecan carpenterworm (Cossula magnifica) are among the more serious insect enemies of mockernut. The hickory bark beetle probably destroys more mockernut trees of sawtimber size than any other insect. The hickory spiral borer kills many seedlings and young trees, and the pecan carpenterworm downgrades both trees and logs (1). The hickory twig girdler (Oncideres cingulatus) attacks both small and large trees.

Although Datana angusii, a defoliating caterpillar, attacks mockernut, it is probably of little economic importance. A number of other insects, including Neoclytus mucronatus, Platypus compositus, and Tremex columba attack weak, dying, or dead mockernut hickory (1).

RACES AND HYBRIDS

There is no information on the existence of geographic races in mockernut hickory. Smith (10), in discussing the genetics of hickory, indicates that mockernut is a tetraploid.

Mockernut hickory crosses naturally with pecan (Carya illinoensis) to form Schneck hickory (Carya x schneckii Sarg.) in Illinois and Iowa (8).

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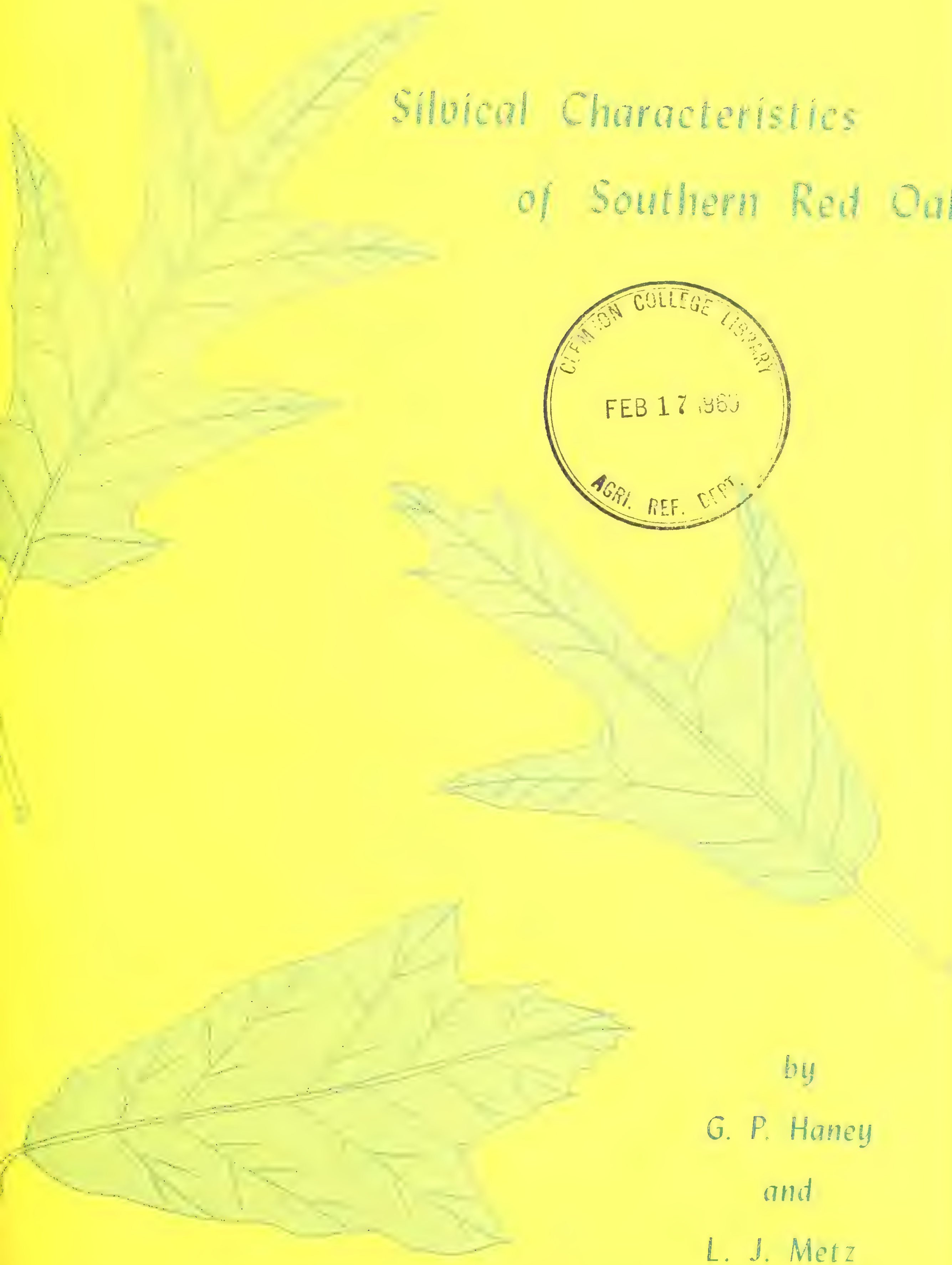
Silvical Characteristics of Southern Red Oak



by

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Station Paper NO. 106

December 1959

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

Southeastern Forest Experiment Station
Asheville, North Carolina

Silvical Characteristics of Southern Red Oak

(Quercus falcata Michx.)

by

G. P. Haney and L. J. Metz

Southern red oak (Quercus falcata Michx.) is one of the commonest of upland southern oaks (fig. 1). Its range extends from southern New Jersey (latitude 40°15' N.) southward to central Florida (latitude 28°30' N.), through the Gulf states to the valley of the Brazos River in Texas (longitude 97°30' W.), and through Arkansas and southeastern Missouri to central Tennessee and Kentucky, and southern Illinois and Indiana (latitude 39°00' N.) (fig. 2). Some southern red oak is also found in southern Ohio and western West Virginia (14, 17). It is comparatively rare in the North Atlantic states, where it is found only in the neighborhood of the coast. However, in the South Atlantic states it is one of the prevalent inhabitants of the forests which cover the Piedmont between the Coastal Plain and the Appalachian Mountains (16). It is less frequently found in the coastal pine belt, and is very rare in the bottomlands of the Mississippi Delta (7).

HABITAT CONDITIONS

CLIMATIC

The climate in which southern red oak grows is a humid, temperate one, characterized by hot summers, mild and short winters, and no distinct dry season (20). The average annual precipitation is between 40 and 50 inches, of which half occurs during the growing season (April through September). Throughout the major portion of the southern red oak range, the average annual temperature is between 60° and 70° F., with daily extremes of near zero to near or above 100°. At the northern edge of its range the average annual temperature is between 50° and 60°, with individual extremes of -10° to 100°.

EDAPHIC

Southern red oak is characteristically an upland species occurring on dry, infertile, sandy or clay soils[1] (6, 7, 8, 11, 21). It is also found widely on sandy loam, sandy clay loam, and silty clay loam soils. Occasionally this species occurs in fertile streambottoms, and here attains its largest size.

1/ Applequist, Martin B. Stand composition of upland hardwood forests as related to soil type in the Duke Forest. 1941. (Unpublished thesis, Duke University, School of Forestry.)

Figure 1.--A southern red oak 74 years old and 21 inches d.b.h. The excellent form, pruning, and horizontal gray stripes (caused by lichens) are characteristic for this species on better sites. West Springs, S. C.

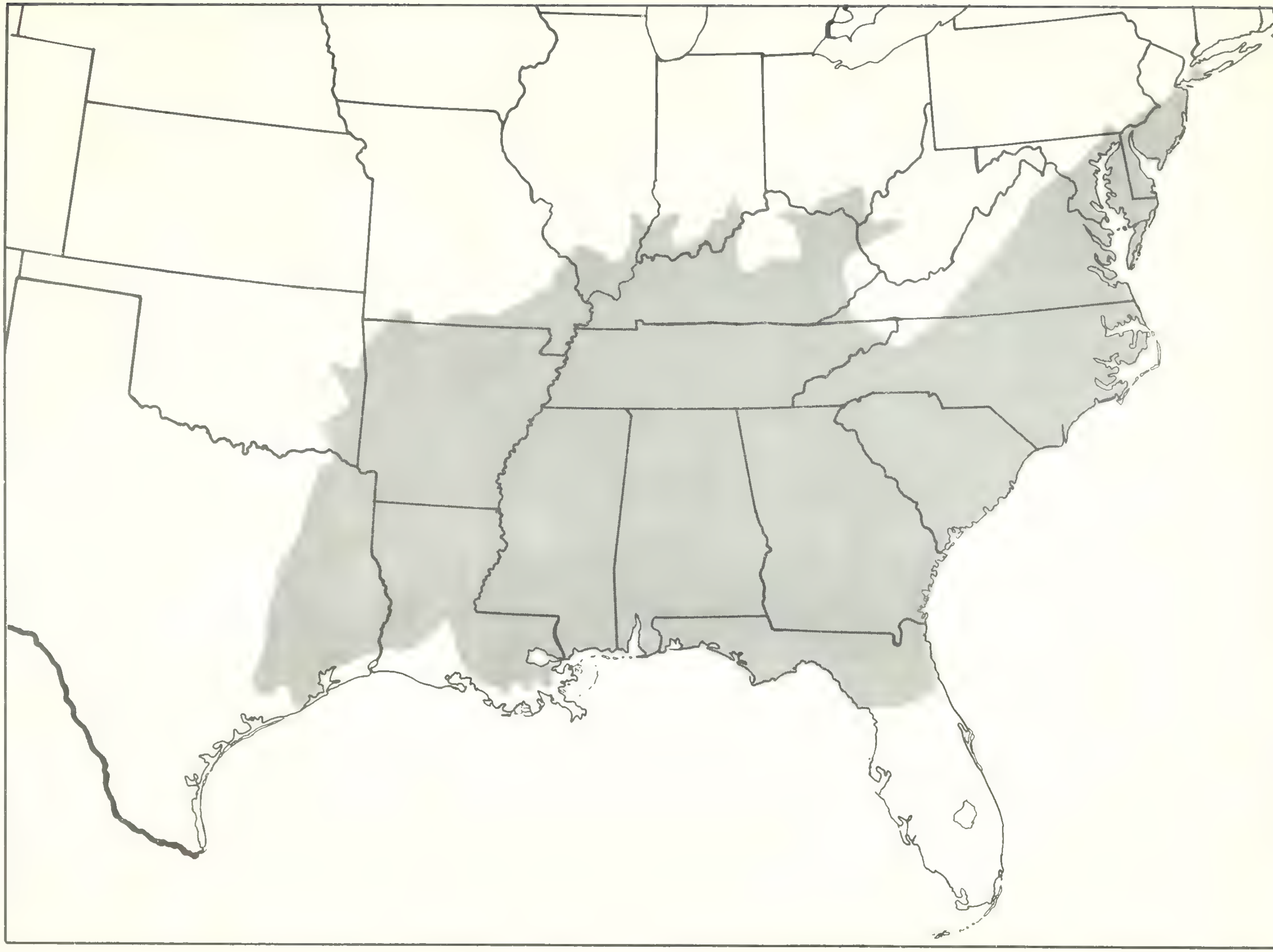

Figure 2.--Botanical range of southern red oak.

PHYSIOGRAPHIC

Throughout its range, southern red oak is most frequently found at elevations between 500 and 2,000 feet above sea level (12). It also occurs at lower elevations in the Coastal Plain. It is characteristically an upland species and usually occurs on the dry ridgetops and upper portions of slopes facing south and west, rather than on the more moist lower slopes and bottomlands, or north and east aspects (11).

BIOTIC

Southern red oak is represented in 13 cover types as defined by the Society of American Foresters (19). It is a major component of the Virginia pine-southern red oak type and the shortleaf pine-oak type, and is a minor element of the following cover types: shortleaf pine-Virginia pine; Virginia pine; loblolly pine-shortleaf pine; loblolly pine; loblolly pine-hardwood; beech-southern magnolia; and scarlet oak. Occasionally it occurs in the longleaf pine type, the swamp chestnut oak-cherrybark oak type, and the post oak-black oak type.

Throughout most of its range, southern red oak is commonly associated with white oak (*Quercus alba*), black oak (*Quercus velutina*), scarlet oak (*Quercus coccinea*), post oak (*Quercus stellata*), blackjack oak (*Quercus marilandica*), sweetgum (*Liquidambar styraciflua*), blackgum (*Nyssa sylvatica*), and hickory (*Carya* spp.). Along the foothills of the Appalachians, Virginia pine (*Pinus virginiana*), pitch pine (*Pinus rigida*), and chestnut oak (*Quercus prinus*) are also common associates. Other common associates are shortleaf pine (*Pinus echinata*) in the Piedmont region, loblolly pine (*Pinus taeda*) in the Coastal Plain region, and both shortleaf and loblolly pine in eastern Texas, southern Arkansas, and Louisiana.

Some occasional associates of southern red oak in various parts of its range are swamp chestnut oak (*Quercus michauxii*), cherrybark oak (*Quercus falcata* var. *pagodaefolia*), white ash (*Fraxinus americana*), slash pine (*Pinus elliottii*), longleaf pine (*Pinus palustris*), yellow-poplar (*Liriodendron tulipifera*), southern magnolia (*Magnolia grandiflora*), American beech (*Fagus grandifolia*), red maple (*Acer rubrum*), flowering dogwood (*Cornus florida*), and persimmon (*Diospyros virginiana*).

LIFE HISTORY

SEEDING HABITS

Flowering of southern red oak occurs during April and May throughout most of its range. The fruit ripens in September and October, the second season after flowering, and seedfall occurs during these months (21) (fig. 3). As in many of the oaks, the acorn is subject to damage by acorn weevils, such as *Curculio baculi*, *Curculio longidens*, *Curculio pardalis*, and *Conotrachelus posticatus*, and the filbertworm, *Melissopus latiferreanus* (2).

Figure 3.--Typical bark, leaf, twig and bud, and fruit of southern red oak.

Seed production usually begins when a tree is about 25 years of age, but maximum production usually occurs between the ages of 50 and 75 years.

Dissemination of acorns by gravity is important on steep slopes. The hoarding habit of squirrels is important in the dispersal of seed of many of the nut trees, and the oaks are no exception (21).

VEGETATIVE PROPAGATION

Southern red oak sprouts vigorously from the stump when the shoot has been killed or cut back (3, 22). Sprouting is more prevalent on young stems 10 inches or less in diameter. This species, like most of the oaks, is difficult to propagate by cuttings (18).

SEEDLING DEVELOPMENT

The seed of southern red oak germinate under natural conditions in the spring following seedfall (21). The specific requirements for the germination and survival of southern red oak seedlings have not been studied, so little can be said concerning seedling establishment. Southern red oak seedlings are damaged and often killed by the hickory spiral borer, *Agrilus arcuatus* var. *torquatus*, and the oak borer, *Aneflomorpha subpubescens* (2).

SAPLING STAGE TO MATURITY

At maturity, southern red oak is a medium-sized tree, usually from 70 to 80 feet in height and 2 to 3 feet in diameter. When growing under forest conditions it develops a long, straight trunk and upward reaching limbs that form a high, rounded crown (4). Maximum age attained is about 150 years.

No data on growth rates and yields have ever been compiled for southern red oak.

Baker (1) rates southern red oak as intermediate in tolerance when compared to its associates. However, Jemison and Hepting (12) rate it as intolerant.

Southern red oak is susceptible to injury by fire because of its thin bark, and as a result of fire scars and other injuries, this species is often subject to heart rots (5). Cankers and rot caused by *Polyporus hispidus* are common on southern red oak. Other common rot fungi affecting this species include *Hydnum erinaceus*, *Polyporus sulphureus*, *P. obtusus*, *Fomes Everhartii*, *F. Calkinsii*, and *Daedalea quercina* (9).

Southern red oak is also susceptible to oak wilt, caused by *Ceratocystis fagacearum*. Trees attacked by this fungus may die within a month or two after the first symptoms become visible.

Oak leaf blister, caused by Taphrina caerulescens (10), and anthracnose, caused by Gnomonia veneta, are common during some seasons.

Grano[2] has noted that epicormic branching is very profuse on southern red oak, especially in crop trees recently released. This reduces the quality of the timber and suggests that good quality will depend on dense stands.

Southern red oak is readily susceptible to borers and bark scarrers when trees are wounded or growing on poor sites (15). Wood-boring insects attacking this species are Agrilus bilineatus, Corthylus columbianus, and Cossula magnifica. The defoliators, Anisota senatoria and Anisota stigma, also do considerable damage (2).

RACES AND HYBRIDS

The races of southern red oak have not been established.

Little (13) recognizes two varieties and eight hybrids of southern red oak. The varieties are the typical southern red oak (Quercus falcata var. falcata), which has been the main subject of this paper, and cherrybark oak (Quercus falcata var. pagodaefolia). Cherrybark oak is important commercially in the Coastal Plain. The hybrids are as follows:

Quercus X anceps Palmer (Quercus falcata X imbricaria)

Quercus X beaumontiana Sarg. (Quercus falcata X laurifolia)

Quercus X blufftonensis Trel. (Quercus falcata X laevis)

Quercus X garlandensis Palmer (Quercus falcata X nigra)

Quercus X joorii Trel. (Quercus falcata X shumardii)

Quercus X ludoviciana Sarg. (Quercus falcata X phellos)

Quercus X subintegra Trel. (Quercus falcata X incana)

Quercus X willdenowiana (Dippel) Zabel (Quercus falcata X velutina)

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Yield of Old-Field Slash Pine Plantations

by

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INTRODUCTION

There are 500,000 acres of planted slash pine in the Georgia middle coastal plain and the Carolina Sandhills, with the oldest plantations dating back 25 years or more to early Civilian Conservation Corps days. Although the present plantation acreage is substantial, it is expected to expand considerably in the near future. Georgia, for instance, produced about 200,000,000 slash pine seedlings in 1958, many of which were planted in the middle coastal plain area.

The management of existing plantations and the establishment of new plantations should be based upon the experience of the past 25 years. The Southeastern Forest Experiment Station, through the Cordele and Charleston Research Centers, has evaluated the wood yield potentials in relation to site productivity, age, spacing, survival, and degree of utilization.[1]

THE STUDY AREA

The study covered 43 counties of the Georgia middle coastal plain and 14 in the Carolina Sandhills (fig. 1). The Georgia area is characterized by a level to rolling topography dissected by many intermittent streams. Topographic conditions of the Carolina Sandhills vary greatly, ranging from deep sand ridges to low bog areas. The major soils of both areas are sands and loamy sands of the Norfolk, Marlboro, and Lakeland groups. The soil series most frequently encountered were Norfolk, Lakeland, Kershaw, Tifton, and Gilead.

The plantations sampled were mostly in old fields. These fields generally represent the poorest agricultural land, but often are more fertile than the surrounding woodland sites.

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[1] Cooperation of the South Carolina Commission of Forestry; Georgia Forestry Commission; North Carolina Department of Conservation and Development; Duke University School of Forestry; West Virginia Pulp and Paper Company; and Savannah River Project, Atomic Energy Commission is gratefully acknowledged. Cooperators' assistance in locating plots, in planning, and in monetary and professional aid made this project possible.

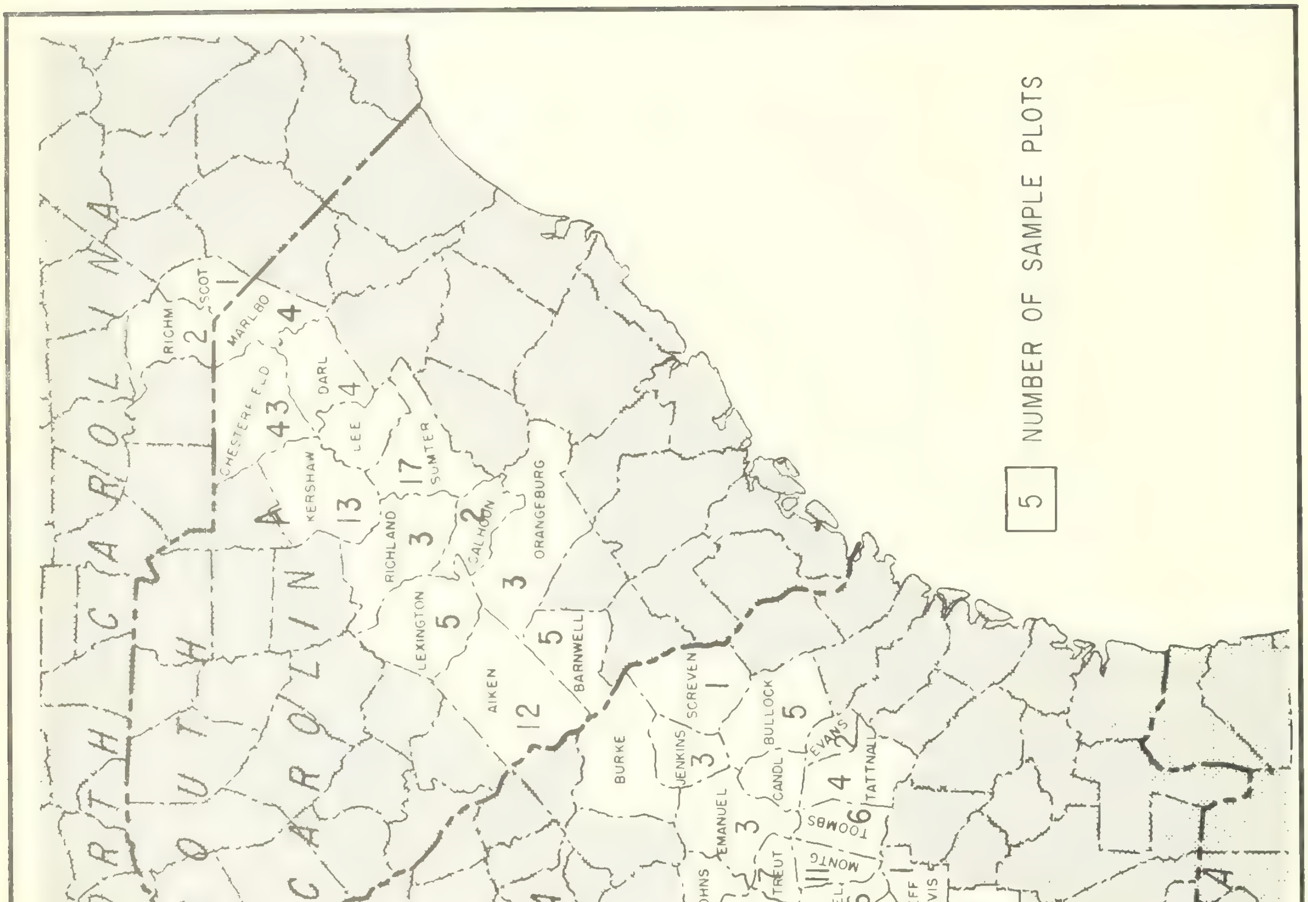

Figure 1.--Distribution of sample plots by counties.

STUDY METHODS

The study involved three phases: (1) The construction of volume tables from data collected on or near the sample plots; (2) the construction of site index curves suitable for calibrating sites on the basis of heights of dominant and codominant trees at 25 years of age; and (3) the establishment of wood yields in cubic feet in relation to age, site index, and stand density.

Field work for the yield study was completed in the summers of 1956 and 1957. The field crews also collected soils and wood-weight information that will be fully reported in separate publications. The soils data applicable to this study are presented in this publication.

VOLUME TABLE CONSTRUCTION

Five hundred and fifty-three trees were felled and measured for constructing volume tables. Cubic volumes, inside and outside bark, were determined for each tree to 4-inch, 3-inch, and 2-inch minimum top diameters outside bark. These data were then subjected to multiple regression analysis, and of the several relationships tested, the product of diameter at breast height squared times total height accounted for about 98 percent of the variation. The equations developed by this analysis appear below.

Top Diameter 4.0 Inches Outside Bark

$$\text{Cubic foot volume (outside bark)} = 0.002706\ D^2H - 1.045389$$

$$\text{Cubic foot volume (inside bark)} = 0.002157\ D^2H - 1.093180$$

Top Diameter 3.0 Inches Outside Bark

$$\text{Cubic foot volume (outside bark)} = 0.002668\ D^2H - 0.396148$$

$$\text{Cubic foot volume (inside bark)} = 0.002135\ D^2H - 0.693239$$

Top Diameter 2.0 Inches Outside Bark

$$\text{Cubic foot volume (outside bark)} = 0.002668\ D^2H - 0.128974$$

$$\text{Cubic foot volume (inside bark)} = 0.002136\ D^2H - 0.497202$$

D = diameter breast high (in inches)

H = total tree height (in feet)

Volumes calculated by these equations appear in tables 1 and 2 in the Appendix.

SITE INDEX CURVES

Site values used in evaluating yield in relation to site quality were developed from height and age data collected on each sample plot. For the construction of site index curves, average tree height was determined by measuring the heights of dominant or codominant trees. Using these data, with the reciprocal of age as the independent variable, the following height-age equation was derived by regression analysis:

$$\text{Logarithm of height} = -\ 5.40638\left(\frac{1}{\text{Age}}\right) + 2.0258$$

The equation was then arranged in the following form to obtain site values based on age 25:

$$\text{Log site index} = \text{logarithm of height} - 5.40638\left(\frac{1}{25} - \frac{1}{\text{Age}}\right)$$

The curves in figure 2 were developed from this equation. They are based on an index age of 25 and must not be confused with 50-year index curves developed for natural slash pine stands.

To find the site index of a slash pine planting between the ages of 10 and 25 years, it is only necessary to determine the plantation age and the average height of the dominant and codominant trees and apply this information to the curves in figure 2. Table 3 shows the average height of the dominant stand to be expected on different sites at various ages.

SOIL SITE INDEX

The soil site index table may be used to determine site index for unplanted land (table 4). The use of the table requires measurements of the thickness of the A_1 (surface) horizon and the depth to a fine textured horizon. For areas in the Georgia middle coastal plain, section A of table 4 applies; in the Carolina Sandhills, section B should be used. These soil-site index tables are derived from related work by C. E. McGee and Clarke Row, summarized in unpublished masters theses at Duke University, 1957 and 1958 respectively.

CUBIC YIELDS

In order to establish the relationship of yield to age, site index, spacing, survival, and degree of utilization, 308 temporary sample plots were established (fig. 1). Plots were selected to obtain adequate geographic coverage. Their distribution in relation to age, spacing, and site is shown in tables 5, 6, and 7. A high percentage of plots fall within a narrow site range despite an effort to sample a full range of sites. Consequently, the authors feel there are few successful old-field plantations on areas with site indexes less than 50 feet at 25 years. Suitable plantations over 20 years of age were also limited in number because many had been thinned or worked for naval stores. Since both treatments affect growth and yield, plantations so affected could not be used.

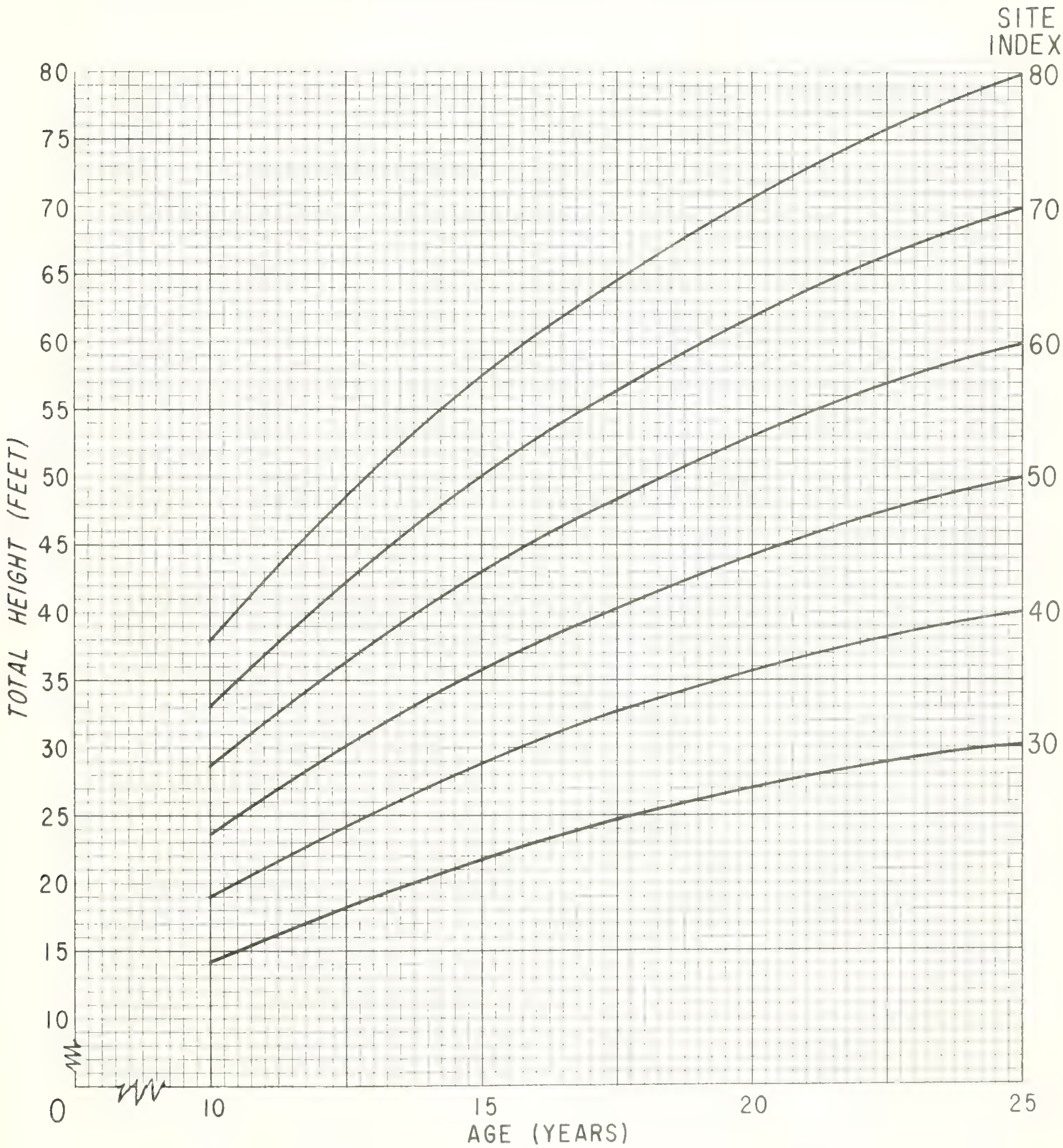

Figure 2.--Site curves at an index age of 25 years for old-field slash pine plantations of the middle coastal plain of Georgia and the Carolina Sandhills.

Selection of Yield Plots

Plantations were considered suitable for sampling when there were no recognizable factors affecting growth other than those being measured. Plantations included in the sampling had to meet the following specifications:

1. Be at least 9 years of age.
2. Show no evidence of thinning.
3. Be unburned.
4. Be unpruned.
5. Show no evidence of heavy disease or insect attack.
6. Have fair survival and good distribution.
7. Show no evidence of interplanting.
8. Be void, or nearly so, of wildlings.

To permit the measurement of approximately the same number of trees per plot, a variable plot size containing about 64 trees (living and dead) was used. The usual plot layout was 8 rows by 8 rows.

Plot Measurements

Separate records were made for each plot as follows:

1. Age of the plantation. Age was determined from increment borings at a height of 1 foot, or from cut trees.
2. Original spacing.
3. Plot dimensions.
4. A complete tree tally by 1-inch diameter classes.
5. On each plot the first and eighth trees (or the first and last, if there were not eight present) in each diameter class were also measured for total height in feet and d.b.h. to nearest tenth inch.

Plot Volume Determination

The first step in calculating plot volumes in cubic feet was the development of an equation for estimating heights by diameter classes on each plot. The height-diameter data were analyzed by regression methods and the following equation developed:

$$\text{Height} = b_o + b_1D + b_2D^2 + b_3D^3$$

where D = diameter at breast height. The coefficients in this equation were determined for each plot. Heights by diameter classes on each plot were then calculated and the diameter-class volumes determined. Total plot volume was computed by multiplying each diameter-class volume by the number of trees in the particular diameter class. Plot volumes were then adjusted to an acre basis.

Statistical Analysis

Analysis of the cubic volume data was by conventional regression technique, which established the following variables as highly significant:

The reciprocal of plantation age.
Site index (height at age 25 of dominant stand).
The logarithm of effective space per tree (original space per tree divided by percent survival).
The reciprocal of site index.

These variables account for 86 percent of the variation about the mean.

A number of other variables and interactions were tested; because their inclusion did not improve the estimating equations, they were omitted.

The yield equations for different degrees of utilization are as follows:

Top Diameter 4.0 Inches Outside Bark

$$\text{Log of yield in cubic feet, outside bark} = 8.9538389 - 17.80865\left(\frac{1}{\text{Age}}\right) - 0.018488158\,(\text{Site Index}) - 0.44864\log\left(\frac{\text{Square feet per tree}}{\text{Survival (in percent)}}\right) - 155.47183\left(\frac{1}{\text{Site Index}}\right)$$

$$\text{Log of yield in cubic feet, inside bark} = 9.2796891 - 20.63365\left(\frac{1}{\text{Age}}\right) - 0.019481521\,(\text{Site Index}) - 0.42716\log\left(\frac{\text{Square feet per tree}}{\text{Survival (in percent)}}\right) - 172.25284\left(\frac{1}{\text{Site Index}}\right)$$

Top Diameter 3.0 Inches Outside Bark

$$\text{Log of yield in cubic feet, outside bark} = 8.4847192 - 14.79800\left(\frac{1}{\text{Age}}\right) - 0.016958973\,(\text{Site Index}) - 0.48084\log\left(\frac{\text{Square feet per tree}}{\text{Survival (in percent)}}\right) - 136.32887\left(\frac{1}{\text{Site Index}}\right)$$

$$\text{Log of yield in cubic feet, inside bark} = 8.6636675 - 16.83688\left(\frac{1}{\text{Age}}\right) - 0.017773496\,(\text{Site Index}) - 0.45630\log\left(\frac{\text{Square feet per tree}}{\text{Survival (in percent)}}\right) - 148.29603\left(\frac{1}{\text{Site Index}}\right)$$

Top Diameter 2.0 Inches Outside Bark

$$\text{Log of yield in cubic feet, outside bark} = 8.5148781 - 13.96498\left(\frac{1}{\text{Age}}\right) - 0.017656104\,(\text{Site Index}) - 0.494811 \log\left(\frac{\text{Square feet per tree}}{\text{Survival (in percent)}}\right) - 135.53031\left(\frac{1}{\text{Site Index}}\right)$$

$$\text{Log of yield in cubic feet, inside bark} = 8.66324265 - 15.67807\left(\frac{1}{\text{Age}}\right) - 0.018599315\,(\text{Site Index}) - 0.46887 \log\left(\frac{\text{Square feet per tree}}{\text{Survival (in percent)}}\right) - 146.42897\left(\frac{1}{\text{Site Index}}\right)$$

Tables 8 to 13 present volume yields calculated by means of these equations for the various age, site, and stand density categories. The survival percentages used in computing these tables are given in table 14.

Use of the Yield Tables

The yield tables provide an estimate of the potential wood production capacity for plantations under varying conditions of site, age, spacing, and top utilization limits. When the tables are used to estimate the actual yield obtainable from plantations where mortality occurs in clusters, some adjustment of the tabular yields may be required. Such adjustments are necessitated because the sample plots contained no openings or voids of measurable size. Trees often tend to die in groups, however, leaving openings or voids of measurable size within the plantation. To arrive at a reasonable yield estimate, these voids must be accounted for in the total plantation acreage.

Small openings involving a single row or groups of four trees or less could be ignored, but in larger groups the vacant space should be subtracted from the plantation acreage. If recent aerial photographs are available, the opening can be mapped out. If the area must be computed from ground measurements, the dimension of the opening should be measured from the crown edges instead of from the trunks. This would not only match the area as measured on photographs, but would also allow for the growth response of the trees on the periphery of the opening.

For use in plantations with random mortality differing appreciably from that on which the tables are based, some adjustment in the calculated yields will be necessary. A 3-percent adjustment should be made in the tabular yield for each 5-point (5 percent) variation in survival from that on which the calculated yield is based. This applies to all the yield tables.

To illustrate this adjustment, consider a 15-year-old 6 x 6 planting in which mortality is well distributed throughout the stand and survival is 50 percent. Table 14 indicates that the tabled yield estimates for 15-year-old plantations spaced 6 x 6 were prepared using 70 percent survival. The percentage adjustment is then calculated as follows:

$$\frac{50\% - 70\%}{5\%} \times 3\% = -12\%$$

In this case, the tabular yields would be decreased 12% to account for mortality.

The yield table values are in cubic feet. For cordwood estimates a converting factor of 92 cubic feet of wood and bark per standard cord of 128 cubic feet may be used. This is based on supplemental measurements at two pulpmills as the wood arrived by railway car. If estimates by weight are desired, a conversion factor of 55 pounds per cubic foot is recommended. This factor is the ratio of the weight of wood plus bark to outside bark cubic foot volume.

The effect of age, site, and stand density on diameter growth is illustrated in table 15. These values were established by regression analysis, and the final estimating equation reads as follows:

$$\begin{aligned}\text{Logarithm of d.b.h.} &= 0.650712 + 0.000219\ (\text{Age x Site Index}) \\ &\quad - 0.234544\ (\text{Logarithm Number of Trees Per Acre}) \\ &\quad + 0.314215\ (\text{Logarithm Site Index})\end{aligned}$$

These variables account for 93.5 percent of the variation.

APPENDIX

Tables 1 and 2--Cubic foot volume tables.

Table 3--Height of dominant stand by age and site index (age 25).

Table 4--Soil site index (age 25).

Table 5--Distribution of sample plots by age and site index (age 25).

Table 6--Distribution of sample plots by age and spacing.

Table 7--Distribution of sample plots by site index (age 25) and spacing.

Tables 8 through 13--Yields of slash pine plantations.

Table 14--Survival by age and stand density.

Table 15--Average diameter at breast height.

Table 1. --Cubic foot volumes (outside bark) for slash pine plantations

TOP DIAMETER 4.0 INCHES OUTSIDE BARK

D.b.h. (Inches)	Total tree height in feet-- 20	25	30	35	40	45	50	55	60	65	70	75
	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	Cubic feet	- - - -	- - - -	- - - -	- - - -	- - - -
5	.31	.65	.98	1.32	1.66	2.00	2.34	2.68	3.01			
6	.90	1.39	1.88	2.36	2.85	3.34	3.83	4.31	4.80	5.29		
7		2.27	2.93	3.60	4.26	4.92	5.59	6.25	6.91	7.57	8.24	
8			4.15	5.02	5.88	6.75	7.61	8.48	9.35	10.21	11.08	11.94
9				6.63	7.72	8.82	9.91	11.01	12.11	13.20	14.30	15.39
10					9.78	11.13	12.48	13.84	15.19	16.54	17.89	19.25
11					12.05	13.69	15.33	16.96	18.60	20.24	21.87	23.51
12					14.54	16.48	18.44	20.39	22.33	24.28	26.23	28.18

TOP DIAMETER 3.0 INCHES OUTSIDE BARK

D.b.h. (Inches)	20	25	30	35	40	45	50	55	60	65	70	75
5	.93	1.27	1.60	1.94	2.27	2.60	2.94	3.27	3.60			
6	1.52	2.00	2.48	2.96	3.44	3.92	4.40	4.88	5.36	5.84		
7		2.87	3.53	4.18	4.83	5.49	6.14	6.79	7.45	8.10	8.76	
8			4.73	5.58	6.43	7.29	8.14	9.00	9.85	10.70	11.56	12.41
9				7.17	8.24	9.33	10.41	11.49	12.57	13.65	14.73	15.81
10					10.28	11.61	12.94	14.28	15.61	16.95	18.28	19.61
11					12.52	14.13	15.74	17.36	18.97	20.59	22.20	23.82
12					14.97	16.89	18.81	20.73	22.66	24.58	26.50	28.42

TOP DIAMETER 2.0 INCHES OUTSIDE BARK

D.b.h. (Inches)	20	25	30	35	40	45	50	55	60	65	70	75
5	1.20	1.53	1.87	2.20	2.54	2.87	3.21	3.54	3.87			
6	1.79	2.27	2.75	3.23	3.71	4.19	4.67	5.15	5.63	6.11		
7		3.14	3.79	4.44	5.10	5.75	6.40	7.06	7.71	8.37	9.02	
8			4.99	5.84	6.70	7.56	8.41	9.26	10.11	10.97	11.82	12.68
9				7.43	8.52	9.60	10.68	11.76	12.84	13.92	15.00	16.08
10					10.54	11.88	13.21	14.54	15.88	17.21	18.55	19.88
11					12.78	14.40	16.01	17.63	19.24	20.86	22.46	24.08
12					15.24	17.16	19.08	21.00	22.92	24.84	26.76	28.67

Table 2. --Cubic foot volumes (inside bark) for slash pine plantations

TOP DIAMETER 4.0 INCHES OUTSIDE BARK

D.b.h. (Inches)	Total tree height in feet--											
	20	25	30	35	40	45	50	55	60	65	70	75
	Cubic feet											
5	--	.25	.52	.79	1.06	1.33	1.60	1.87	2.14			
6	.46	.85	1.24	1.62	2.01	2.40	2.79	3.18	3.57	3.95		
7		1.55	2.08	2.61	3.14	3.66	4.19	4.72	5.25	5.78	6.31	
8			3.05	3.74	4.43	5.12	5.81	6.50	7.19	7.88	8.57	9.26
9				5.02	5.89	6.77	7.64	8.52	9.39	10.26	11.14	12.01
10					7.54	8.61	9.69	10.77	11.85	12.93	14.01	15.08
11					9.35	10.65	11.96	13.26	14.57	15.87	17.18	18.48
12					11.33	12.88	14.44	15.99	17.54	19.10	20.65	22.20

TOP DIAMETER 3.0 INCHES OUTSIDE BARK

D.b.h. (Inches)	20	25	30	35	40	45	50	55	60	65	70	75
5	.37	.64	.91	1.18	1.44	1.71	1.98	2.24	2.51			
6	.90	1.28	1.67	2.05	2.43	2.82	3.20	3.59	3.97	4.36		
7		1.97	2.50	3.02	3.54	4.07	4.59	5.11	5.64	6.16	6.68	
8			3.41	4.09	4.77	5.46	6.14	6.82	7.50	8.19	8.87	9.56
9				5.36	6.22	7.09	7.95	8.82	9.68	10.55	11.41	12.28
10					7.85	8.91	9.98	11.05	12.12	13.18	14.25	15.32
11					9.64	10.93	12.22	13.52	14.81	16.09	17.39	18.68
12					11.60	13.14	14.68	16.22	17.75	19.30	20.83	22.38

TOP DIAMETER 2.0 INCHES OUTSIDE BARK

D.b.h. (Inches)	20	25	30	35	40	45	50	55	60	65	70	75
5	.57	.84	1.10	1.37	1.64	1.91	2.17	2.44	2.71			
6	1.04	1.43	1.81	2.19	2.58	2.96	3.35	3.73	4.12	4.50		
7		2.12	2.64	3.17	3.69	4.21	4.74	5.26	5.78	6.31	6.83	
8			3.60	4.29	4.97	5.65	6.34	7.02	7.70	8.39	9.07	9.76
9				5.56	6.42	7.29	8.15	9.02	9.88	10.75	11.61	12.48
10					8.05	9.12	10.18	11.25	12.32	13.39	14.46	15.52
11					9.84	11.13	12.42	13.72	15.01	16.30	17.59	18.89
12					11.81	13.34	14.88	16.42	17.96	19.49	21.03	22.57

Table 3. --Height of dominant stand by age and site index (age 25)

Age	Site index					
	30	40	50	60	70	80
	Feet					
10	14	19	24	28	33	38
11	16	21	26	31	37	42
12	18	23	29	35	40	46
13	19	25	31	38	44	50
14	20	27	34	40	47	54
15	22	29	36	43	50	57
16	23	30	38	45	52	61
17	24	32	40	47	55	63
18	25	33	41	49	57	66
19	26	34	43	51	60	68
20	27	35	44	53	62	70

Table 4. --Soil site index (age 25) for slash pine plantations on old fields of the Carolina Sandhills and the middle coastal plain of Georgia

Thickness of the A_1 horizon (inches)	Depth to fine textured horizon of--							
	10 inches	20 inches	30 inches	40 inches	50 inches	60 inches	80 inches	100 inches
	Feet							
1	46 / -	47 / -	47 / -	46 / -	45 / -	43 / -	- / -	- /
3	57 / 58	60 / 58	60 / 58	59 / 58	57 / 57	56 / 56	- / 55	- / 45
6	65 / 62	66 / 62	67 / 62	66 / 61	64 / 61	62 / 60	- / 58	- / 56
9	67 / 66	70 / 66	71 / 66	70 / 65	67 / 65	66 / 64	- / 62	- / 60
12	- /	74 / 70	74 / 70	73 / 69	72 / 69	69 / 68	- / 67	- / 64

KEY:
A: Georgia middle coastal plain
B: Carolina Sandhills

Table 5. --Distribution of sample plots by age and site index (age 25)

Age class	Site index						
	30	40	50	60	70	80	Total
	Number						
10	-	2	2	27	12	2	45
13	-	2	5	22	27	3	59
16	2	1	4	49	47	6	109
19	-	1	10	31	36	1	79
22	-	2	1	9	-	-	12
25	-	-	1	1	1	-	3
28	-	-	-	-	1	-	1
Total	2	8	23	139	124	12	308

Table 6. --Distribution of sample plots by age and spacing

Spacing (feet)	Age (years)							
	[illegible]	13	16	[illegible]	22	25	28	Total
	- - -	- - -	- - -	Number	- - -	- - -	- - -	
[illegible]	-	1		-			-	
[illegible]		-		1	-	-	-	1
[illegible]	-		-		1	-	-	1
[illegible]	-	1	1	-	1	-	-	3
[illegible]	1	2	4	4	3	-	-	14
[illegible]	3	6	9	12	[illegible]	-	-	32
[illegible]	3	11	8	11	1	-	-	34
[illegible]	[illegible]	2	5	10		1	-	25
5 x 10	1	1	1	-	-	-	-	3
[illegible]	3	4	12		-	1	-	20
[illegible]	2	3	4	2	-	1	-	12
[illegible]	5	5	21	3	1	-	-	35
[illegible]	2	1	6	3	-	-		12
8 x 10	4	4	12	2	-		-	22
[illegible]	3	[illegible]	2	1	-	-	-	8
10 x 10	3	3	7	8	1	-	-	22
10 x 12	1	3	4	2	1	-	1	15
[illegible]		-	1	-	-	-	-	1
[illegible]	1	[illegible]	3	5	1	-	-	12
12 x 15	1	[illegible]	1	2	-	-	-	5
14 x 14	2	1	2	[illegible]	-	-	-	7
[illegible]		2	2	2	-		-	6
15 x 15		2	1	1	-	-	-	4
12 x 20		1	1		-	-	-	2
16 x 16	-	-	1	4	-	-	-	5
17 x 17		-	1	3	-	-	-	4
18 x 20		-	-	1	-	-	-	1
20 x 20		1	-	-	-	-	-	1
Total	45	59	109	79	12	3	1	308

Table 7. --Distribution of sample plots by site index (age 25) and spacing

Spacing (feet)	Site index						
	30	40	50	60	70	80	Total
				Number			
4 x 2	-	-	1	-	-	-	1
4 x 4	-	-	-	1	-	-	1
4 x 5	-	-	-	1	-	-	1
5 x 5	-	-	-	3	-	-	3
5 x 6	-	-	3	6	5	-	14
6 x 6	-	-	5	17	10	-	32
6 x 7	-	-	4	20	9	1	34
6 x 8	-	2	2	11	9	1	25
5 x 10	-	-	-	1	2	-	3
7 x 8	1	-	-	9	9	1	20
6 x 10	-	-	3	4	5	-	12
8 x 8	1	-	3	12	18	1	35
6 x 12	-	-	-	6	6	-	12
8 x 10	-	2	-	8	12	-	22
8 x 12	-	1	1	4	-	2	8
10 x 10	-	2	1	9	9	1	22
10 x 12	-	-	-	7	7	1	15
7 x 20	-	-	-	1	-	-	1
12 x 12	-	-	-	5	6	1	12
12 x 15	-	-	-	3	2	-	5
14 x 14	-	-	-	3	3	1	7
10 x 20	-	-	-	2	3	1	6
15 x 15	-	-	-	2	2	-	4
12 x 20	-	-	-	1	1	-	2
16 x 16	-	-	-	2	3	-	5
17 x 17	-	-	-	1	2	1	4
18 x 20	-	-	-	-	1	-	1
20 x 20	-	1	-	-	-	-	1
Total	2	8	23	139	124	12	308

Table 8. --Yields (outside bark) of slash pine plantations of the middle coastal plain of Georgia and the Carolina Sandhills 1/

Age (years)	Original spacing	Site index (age 25)							
		40	45	50	55	60	65	70	75
	Feet	- - - - - - - - - - - - - Cubic feet per acre - - - - - - - - - - - - -							
10	6 x 6	61	135	240	369	511	657	788	912
	6 x 7	57	126	225	346	478	616	738	852
	6 x 8	54	119	212	327	451	582	697	809
	8 x 8	48	106	188	289	400	515	617	712
	8 x 10	44	96	171	263	365	469	562	648
	10 x 10	40	88	156	241	333	428	514	593
	15 x 15	29	65	115	177	244	315	377	435
15	6 x 6	237	522	926	1426	1972	2539	3042	3526
	6 x 7	222	488	868	1336	1847	2378	2849	3303
	6 x 8	209	461	819	1262	1745	2246	2691	3120
	8 x 8	186	409	726	1118	1546	1989	2384	2761
	8 x 10	169	372	662	1019	1409	1814	2174	2518
	10 x 10	155	340	605	931	1287	1657	1986	2303
	15 x 15	114	250	443	684	946	1218	1459	1699
20	6 x 6	463	1020	1812	2790	3858	4967	5952	6800
	6 x 7	434	955	1697	2612	3612	4650	5571	6388
	6 x 8	410	902	1603	2468	3412	4393	5230	5990
	8 x 8	363	799	1419	2185	3022	3891	4595	5260
	8 x 10	331	729	1295	1994	2757	3550	4190	4775
	10 x 10	302	666	1183	1822	2519	3210	3800	4315
	15 x 15	222	490	871	1341	1834	2310	2790	3275

1/ Includes all trees 4.6 inches in diameter and larger to a top diameter 4.0 inches outside bark.

Table 9. --Yields (inside bark) of slash pine plantations of the middle coastal plain of Georgia and the Carolina Sandhills 1/

Age (years)	Original spacing	Site index (age 25)							
		40	45	50	55	60	65	70	75
	Feet	- - - - - - - - - - - - - Cubic feet per acre - - - - - - - - - - - - -							
10	6 x 6	25	62	118	193	280	376	464	552
	6 x 7	24	58	111	182	263	353	436	518
	6 x 8	23	55	106	172	250	334	413	493
	8 x 8	20	49	94	153	222	297	368	437
	8 x 10	19	45	86	141	204	272	337	399
	10 x 10	17	41	79	129	187	250	310	367
	15 x 15	13	31	59	96	139	186	231	298
15	6 x 6	122	297	570	930	1346	1802	2228	2655
	6 x 7	115	280	535	873	1265	1693	2092	2514
	6 x 8	109	265	507	830	1197	1603	1981	2382
	8 x 8	97	236	451	737	1068	1428	1766	2120
	8 x 10	89	216	414	675	978	1308	1687	1942
	10 x 10	82	198	380	619	897	1200	1484	1783
	15 x 15	61	148	283	462	669	895	1106	1330
20	6 x 6	268	650	1243	2028	2938	3931	4700	5460
	6 x 7	252	610	1167	1905	2759	3692	4490	5205
	6 x 8	238	578	1106	1804	2613	3487	4200	4900
	8 x 8	212	515	985	1607	2328	3091	3718	4328
	8 x 10	195	472	902	1473	2134	2810	3428	3910
	10 x 10	179	433	828	1351	1958	2587	3173	3683
	15 x 15	133	323	619	1009	1439	1897	2360	2775

1/ Includes all trees 4.6 inches in diameter and larger to a top diameter 4.0 inches inside bark.

Table 10. --Yields (outside bark) of slash pine plantations of the middle coastal plain of Georgia and the Carolina Sandhills 1/

Age (years)	Original spacing	Site index (age 25)							
		40	45	50	55	60	65	70	75
	Feet	Cubic feet per acre							
10	6 x 6	127	252	414	599	789	976	1134	1291
	6 x 7	119	234	386	558	735	910	1056	1180
	6 x 8	112	221	363	525	692	856	994	1125
	8 x 8	98	194	318	460	607	751	872	981
	8 x 10	88	176	288	417	550	680	790	889
	10 x 10	81	159	262	379	499	617	727	824
	15 x 15	57	114	188	272	358	443	545	654
15	6 x 6	389	772	1267	1835	2417	2989	3473	3918
	6 x 7	363	720	1181	1710	[illegible]	2786	3238	3653
	6 x 8	342	677	1111	1608	2119	2621	3045	3436
	8 x 8	300	595	975	1413	1860	2302	2675	3014
	8 x 10	272	539	883	1279	1685	2085	2422	2731
	10 x 10	247	489	802	1161	1529	1892	2199	2480
	15 x 15	177	351	577	835	1099	1360	1580	1787
20	6 x 6	679	1344	2206	3193	4206	5204	6046	6905
	6 x 7	632	1252	2055	2975	3919	4848	5680	6512
	6 x 8	595	1178	1934	2799	3687	4532	5300	6120
	8 x 8	522	1035	1698	2458	3238	4005	4654	5300
	8 x 10	473	938	1539	2228	2934	3630	4218	4830
	10 x 10	430	851	1397	2022	2664	3296	3886	4410
	15 x 15	309	613	1006	1456	1917	2387	2860	3369

1/ Includes all trees 4.6 inches in diameter and larger to a top diameter 3.0 inches outside bark.

Table 11. --Yields (inside bark) of slash pine plantations of the middle coastal plain of Georgia and the Carolina Sandhills 1/

Age (years)	Original spacing	Site index (age 25)							
		40	45	50	55	60	65	70	75
	Feet	Cubic feet per acre							
10	6 x 6	62	130	225	340	462	587	696	800
	6 x 7	58	122	210	318	432	549	651	747
	6 x 8	54	115	199	300	408	518	615	708
	8 x 8	48	102	176	265	360	458	543	622
	8 x 10	44	93	160	241	328	417	495	565
	10 x 10	40	85	146	220	299	380	451	516
	15 x 15	29	62	107	160	218	277	350	414
15	6 x 6	220	468	808	1218	1657	2104	2497	2870
	6 x 7	207	438	756	1139	1550	1969	2336	2685
	6 x 8	195	413	714	1075	1462	1857	2204	2533
	8 x 8	172	365	631	950	1293	1642	1949	2237
	8 x 10	157	332	574	865	1177	1495	1774	2037
	10 x 10	143	303	524	789	1074	1363	1618	1859
	15 x 15	105	221	383	576	785	997	1183	1372
20	6 x 6	416	881	1523	2295	3121	3965	4750	5510
	6 x 7	389	824	1424	2146	2919	3707	4520	5235
	6 x 8	367	778	1344	2025	2755	3510	4225	4950
	8 x 8	324	687	1188	1790	2435	3093	3760	4393
	8 x 10	296	627	1082	1630	2218	2845	3450	3995
	10 x 10	270	571	987	1488	2023	2620	3239	3750
	15 x 15	197	418	722	1089	1481	1956	2418	2890

1/ Includes all trees 4.6 inches in diameter and larger to a top diameter 3.0 inches inside bark.

Table 12. --Yields (outside bark) of slash pine plantations of the middle coastal plain of Georgia and the Carolina Sandhills 1/

Age (years)	Original spacing	Site index (age 25)							
		40	45	50	55	60	65	70	75
	Feet	Cubic feet per acre							
10	6 x 6	153	300	487	697	908	1112	1279	1431
	6 x 7	143	279	453	648	845	1034	1190	1350
	6 x 8	134	262	426	609	793	971	1117	1263
	8 x 8	117	229	372	532	694	849	977	1088
	8 x 10	106	207	336	481	626	767	882	980
	10 x 10	96	187	304	435	567	694	798	889
	15 x 15	68	133	216	309	403	493	600	700
15	6 x 6	441	863	1399	2002	2609	3195	3676	4103
	6 x 7	410	802	1301	1862	2427	2972	3419	3817
	6 x 8	386	753	1222	1748	2279	2790	3209	3585
	8 x 8	337	660	1069	1530	1994	2441	2809	3133
	8 x 10	304	595	965	1382	1801	2205	2536	2831
	10 x 10	276	539	874	1251	1630	1996	2296	2563
	15 x 15	196	384	622	890	1160	1420	1634	1829
20	6 x 6	744	1454	2357	3374	4397	5384	6212	7000
	6 x 7	692	1352	2192	3137	4088	5006	5835	6585
	6 x 8	650	1270	2059	2946	3840	4702	5500	6200
	8 x 8	568	1110	1801	2577	3359	4112	4780	5410
	8 x 10	513	1003	1627	2329	3035	3717	4340	4937
	10 x 10	465	908	1473	2108	2748	3387	3980	4512
	15 x 15	331	648	1050	1503	2000	2490	2980	3470

1/ Includes all trees 4.6 inches in diameter and larger to a top diameter 2.0 inches outside bark.

Table 13. --Yields (inside bark) of slash pine plantations of the middle coastal plain of Georgia and the Carolina Sandhills 1/

Age (years)	Original spacing	Site index (age 25)							
		40	45	50	55	60	65	70	75
	Feet	Cubic feet per acre							
10	6 x 6	79	164	278	418	551	689	806	914
	6 x 7	74	153	259	384	514	644	753	851
	6 x 8	70	144	244	362	485	607	710	807
	8 x 8	61	127	215	319	427	534	624	706
	8 x 10	56	115	195	290	388	485	567	639
	10 x 10	51	105	178	263	352	441	515	582
	15 x 15	37	76	129	191	255	319	400	465
15	6 x 6	259	537	911	1349	1806	2260	2644	2997
	6 x 7	242	501	851	1260	1687	2111	2469	2799
	6 x 8	227	472	801	1186	1588	1988	2326	2637
	8 x 8	200	417	706	1046	1400	1752	2050	2320
	8 x 10	182	378	641	950	1271	1591	1861	2109
	10 x 10	166	344	583	864	1157	1447	1693	1918
	15 x 15	120	249	422	626	838	1049	1227	1391
20	6 x 6	466	968	1640	2430	3253	4072	4861	5611
	6 x 7	435	904	1531	2268	3037	3800	4580	5302
	6 x 8	410	851	1443	2138	2861	3581	4309	5000
	8 x 8	361	750	1271	1883	2520	3211	3850	4491
	8 x 10	328	681	1155	1710	2290	2866	3470	4055
	10 x 10	298	620	1051	1556	2084	2680	3297	3840
	15 x 15	217	450	763	1130	1546	2014	2489	2979

1/ Includes all trees 4.6 inches in diameter and larger to a top diameter 2.0 inches inside bark.

Table 14. --Survival by age and stand density

Spacing (feet)	Age (years) 10	15	20
	- - - Percent - - -		
6 x 6	73	70	68
6 x 7	74	71	69
6 x 8	74	72	70
8 x 8	75	73	71
8 x 10	76	74	72
10 x 10	78	76	74
15 x 15	88	86	84

Table 15. --Average diameter at breast height of entire stand by age, spacing, and site index (age 25)

Age (years)	Original spacing	Surviving trees per acre	Site index 40	45	50	55	60	65	70	75
	Feet	Number	- - - - - - - - - - - - - Inches							
10	6 x 6	886	3.5	3.8	4.0	4.2	4.4	4.6	4.9	5.2
	6 x 8	672	3.8	4.0	4.3	4.5	4.7	4.9	5.2	5.5
	8 x 8	513	4.0	4.3	4.5	4.8	5.1	5.2	5.6	5.9
	10 x 10	341	4.4	4.7	5.0	5.3	5.6	5.7	6.2	6.5
	12 x 12	249	4.8	5.1	5.4	5.7	6.0	6.2	6.6	7.0
	15 x 15	171	5.2	5.6	5.9	6.2	6.6	6.7	7.2	7.6
15	6 x 6	858	4.0	4.3	4.6	4.9	5.2	5.6	5.9	6.3
	6 x 8	651	4.2	4.6	4.9	5.2	5.6	5.9	6.3	6.7
	8 x 8	497	4.5	4.9	5.2	5.6	5.9	6.3	6.7	7.1
	10 x 10	331	5.0	5.3	5.7	6.0	6.5	7.0	7.4	7.9
	12 x 12	243	5.3	5.7	6.2	6.6	7.0	7.5	8.0	8.4
	15 x 15	167	5.8	6.3	6.7	7.2	7.7	8.2	8.7	9.2
20	6 x 6	830	4.4	4.8	5.2	5.7	6.1	6.6	7.1	7.7
	6 x 8	631	4.7	5.1	5.6	6.1	6.5	7.1	7.6	8.2
	8 x 8	482	5.0	5.5	6.0	6.4	7.0	7.5	8.1	8.7
	10 x 10	322	5.5	6.0	6.5	7.1	7.7	8.3	8.9	9.5
	12 x 12	236	5.9	6.5	7.0	7.6	8.2	8.9	9.6	10.3
	15 x 15	162	6.5	7.1	7.7	8.3	9.0	9.7	10.4	11.2

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Tree Grades Give Accurate Estimate of Second-Growth Yellow-Poplar Values

by

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Tree Grades Give Accurate Estimate of Second-Growth Yellow-Poplar Values

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INTRODUCTION

Thousands of acres of second-growth yellow-poplar are reaching merchantable size every year in the Southern Appalachians. Since the market for roundwood is limited and this large area is in need of thinning, lumber is the logical outlet. But the timber is young, the logs are relatively small, and they contain too low a proportion of heartwood to qualify for FAS grade lumber. Consequently, second-growth poplar still has a stigma of undesirable quality attached to it by local sawmillers and lumber buyers. Furthermore, rangers and other timber appraisers haven't had a real knowledge of what such timber is worth until now, and for that reason haven't been marking such trees for sale. In view of these facts, it became apparent early in 1955 that grade yield information for second-growth yellow-poplar logs and trees was much needed.

As a first step, a preliminary grade yield investigation was made in cooperation with the Bemis Lumber Company at Robbinsville, North Carolina (Study 1). The 69 trees cut for this analysis came from a good yellow-poplar site and yielded a large proportion of No. 1 Common and Better lumber. Consequently, a check examination was made in cooperation with the Carr Lumber Company at Brevard, North Carolina (Study 2). This time an area with a site index averaging 85 feet was examined and 58 trees were cut. The much lower grade yields for the same grades of logs in this study indicated that there might be differences between graders or among sites. A third test was made at the Carr mill (Study 3), using the same lumber grader and sampling 60 yellow-poplars from a site averaging 115 feet. The fourth study was made at the Bemis mill (Study 4) with the same lumber grader used in the first investigation and sampling 49 yellow-poplars from sites ranging from 80 to 120 feet.

STUDY METHODS

The trees for all four studies were cut from national forest lands typical of the Southern Appalachian region. The stands averaged 52 years old, with a range in age for individual trees of 44 to 63 years. Elevations included were from 2,100 feet above sea level to 3,600 feet, approximately the entire altitudinal range in which commercial stands are commonly found (fig. 1).

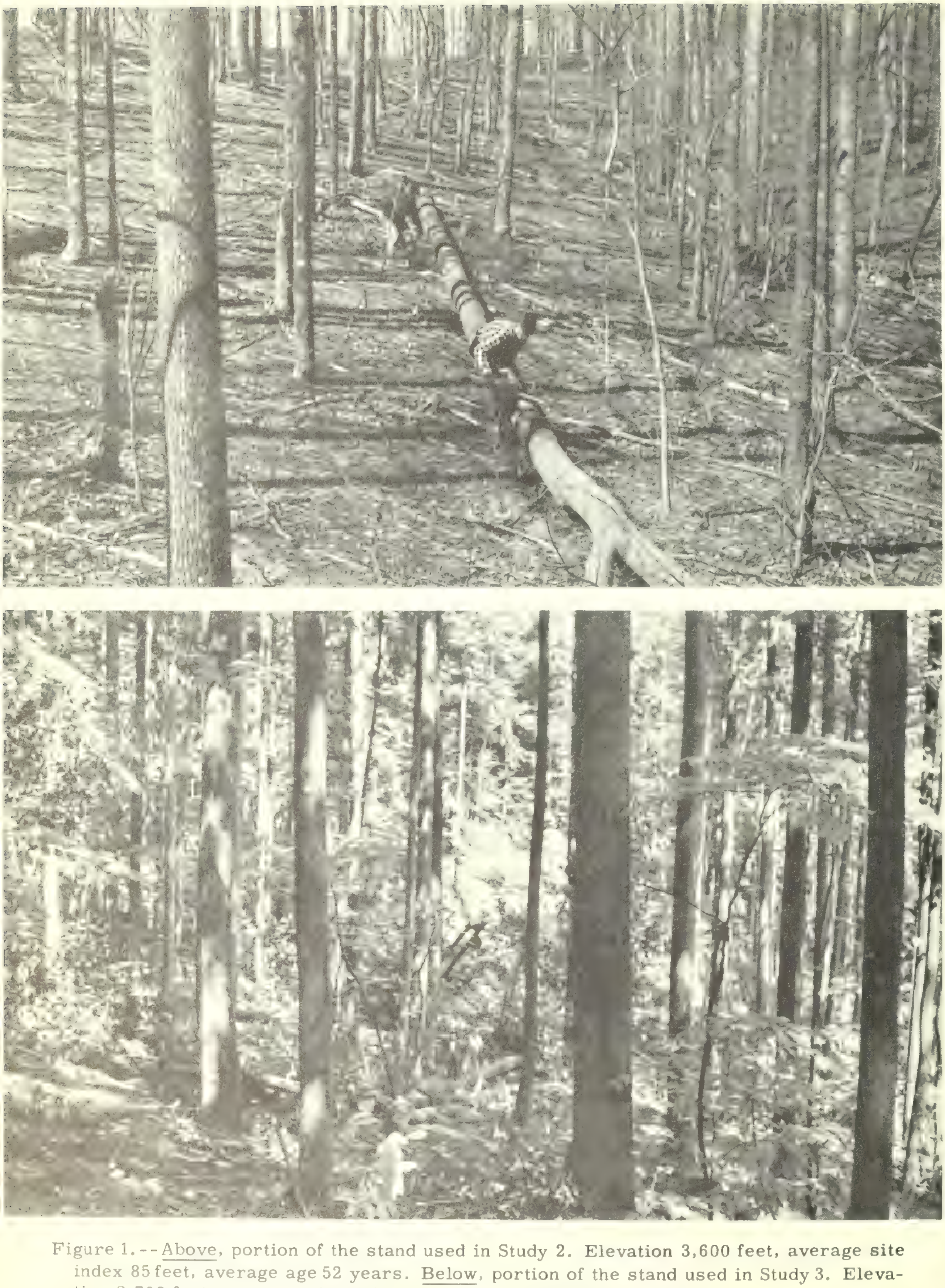

Figure 1.--Above, portion of the stand used in Study 2. Elevation 3,600 feet, average site index 85 feet, average age 52 years. Below, portion of the stand used in Study 3. Elevation 2,700 feet, average site index 115 feet, average age 53 years.

The first grading[1] was an estimate of tree grade made in standing timber, necessarily ignoring end defects. Diameter at breast height was measured, the number of 16-foot logs estimated, and the butt logs were carefully graded (fig. 2). After the trees had been felled and bucked, each log was scaled and the defects were diagrammed by type and location. Each log was then graded on the basis of Forest Products Laboratory hardwood log grades.[2] The bucking was done carefully but not specifically for grade, and actual log lengths were used in scaling and grading. After the logs had been diagrammed and band sawed, the lumber was graded by a National Hardwood Lumber Association inspector and tallied according to dimension and grade. The distribution of logs and trees by grade was as follows:

Logs		Trees	
(Grade)	(Number)	(Grade)	(Number)
1	90	A	77
2	179	B	75
3	223	C	57
4	254	D	27
Total	746		236

Lumber yields by tree size and grade were compiled. We computed quality index values (Q.I.) for each log and each tree, using basic index values reported by Ellertson and Lane,[3] so that the relationships between log size (d.i.b.) and grades could be established with regression techniques.

Synthesized Q.I. values were determined for trees of varying grades and diameters up to 26 inches d.b.h. These values were based on the actual grade of the butt log including end defects, and the assumption that the second and each succeeding log is one grade lower than the preceding log. The tree Q.I. weighted by proportionate volumes was then plotted, curves were constructed, and values tabulated.

RESULTS

Logs and Trees Can Be Tree Graded

Approximately two-thirds of all logs cut were of factory grade, and the remaining third were below factory grade (called 4's). The factory grade logs were all diagrammed and graded. Eighty-five percent of these logs were the same grade after diagramming as when graded in the tree. Furthermore, 82 percent of the trees had been correctly tree graded.[4] Small knots, the most important cause of misgrading standing trees, accounted for 44 percent of the missed cases (table 1).

1/ Campbell, R. A. Tree grades, yields and values for some Appalachian hardwoods. Southeast. Forest Expt. Sta. Paper 9, 26 pp. 1951.

2/ U.S. Forest Products Laboratory. Hardwood log grades for standard lumber. Rpt. D1737. 1949.

3/ B. Ellertson and P. Lane. Lumber price ratios. U. S. Tenn. Val. Authority Div. Forest Relat. Tech. Note 15. 1953.

4/ "Tree grading" is defined as application of Forest Products Laboratory hardwood log grades to the butt 16-foot log in the standing trees, with each succeeding 16-foot log assumed to be a grade lower. A description can be found in the reference cited in footnote 1 in this paper.

Figure 2.--Above, loading logs, Study 3. Factory grade 1 log being loaded, factory grade 3 log in foreground already on truck. Below, railroad carload of logs from Study 1 (good site) near Robbinsville, N. C.

Table 1. --Number and cause of differences between estimated and actual tree grade

Study	Changes: None	Up	Down	Total	Reasons for change: Knots	Log taper	Other 1/	Total
	- - -	- - -	- - -	- - - Number	- - -	- - -	- - -	- - -
Study 1	49	16	4	69	11	8	1	20
Study 2	47	1	1	49	--	1	1	2
Study 3	45	12	1	58	6	2	5	13
Study 4	52	5	3	60	2	--	6	8
All	193	34	9	236	19	11	13	43
Percent	82	14	4	100	44	26	30	100

1/ Other includes 2 log scars, 2 birdpeck, 1 rot, 2 ridges, and 6 unknown.

It was found that exterior indications of adventitious buds, bird pecks, and grubs are not defects in second-growth yellow-poplar logs and trees (fig. 3), since graded lumber cut from faces with these surface aberrations showed no degrade.

Second-Growth Yellow-Poplar Has Quality Yield

Quality index values for both logs and trees have been computed on the basis of lumber yields and values (table 2). The variation within and between grade averages can best be compared by reference to the quality index values.

Table 2. --Comparative grade yields of second-growth yellow-poplar lumber by log grade 1/

Log grade	Study	Q. I.	Lumber grade: FAS	Sel.	Sap	1C	2A	2B	3C
			- - -	- - -	- - -	Percent	- - -	- - -	- - -
1	Study 1	113	4	26	18	35	13	3	1
	Study 2	93	--	--	28	27	35	9	1
	Study 3	106	1	10	34	24	29	1	1
	Study 4	93	1	13	1	52	28	4	1
	Average	101	1	13	20	35	26	4	1
2	Study 1	96	2	11	7	43	22	11	4
	Study 2	80	--	--	8	25	41	24	2
	Study 3	86	--	2	12	33	45	7	1
	Study 4	81	--	3	--	46	41	9	1
	Average	85	--	4	7	37	37	13	2
3	Study 1	76	--	2	1	40	27	25	5
	Study 2	61	--	--	--	9	41	46	4
	Study 3	69	--	--	2	18	50	29	1
	Study 4	68	--	--	--	21	57	21	2
	Average	68	--	--	1	22	44	30	3
4	Study 1	59	--	--	--	13	30	44	13
	Study 2	54	--	--	--	1	27	65	7
	Study 3	57	--	--	--	5	29	58	8
	Study 4	62	--	--	--	7	54	32	7
	Average	58	--	--	--	7	35	50	8

1/ Based on a total of 746 logs (86,740 bd. ft. lumber).

Figure 3. --Above, occluded grub hole (bark scar) of no importance, Study 1, near Robbinsville, N. C. Below, deck of assorted logs from good site, Study 3, Brevard, N. C. Bird peck on logs in foreground did not lower the grade.

When average grade yields and corresponding Q.I. values were used as a base (table 2), this variation in value was found to be greatest in the top grade (No. 1 logs), amounting to as much as 20 Q.I. points (93 to 113). This difference expressed in dollars per M b.f., with No. 1 common lumber values at \$100 per M b.f., would amount to \$20. In grade 2 logs the difference from the mean quality index of 85 is a plus \$11 per M b.f. to a minus \$5, and in grade 3 it ranges from plus \$8 to a minus \$7 from the mean Q.I. of 68. In grade 4 it is only $\pm$ \$4 from a mean quality index of 58.

The relationship of estimated tree Q.I. to d.b.h. by grade is illustrated in figure 4. Statistical analyses of log values show that the estimated Q.I. values differed from the actual Q.I. values in only 3 out of the 12 tests made (3 studies and 4 log grades). Furthermore, in only one case, grade B logs of Study 1, did the difference amount to more than $\pm$ 4 percent. In this case the variation amounted to $\pm$ 8 percent. Statistically, the estimated Q.I. values for trees did not differ significantly from the actual Q.I. values.

Site Affects Quality Index of the Better-Grade Logs and Trees

In each study, logs of each grade obtained from trees of known site index were analyzed separately. Grade 1 logs showed a difference by site of over 20 Q.I. points within the sampled range (site indexes 70 to 130). Grade 2 logs showed 7 Q.I. points difference between the same size logs from good and poor sites. Grade 3 logs had 11 Q.I. points difference between logs of the same size from good versus poor sites. The relative values of grade 4 logs were low, and apparent differences were insignificant.

Grade 1, 2, and 4 logs did not differ in Q.I. points between mills. Only in the case of grade 3 logs did the mill prove significant.

The effect of site on logs and tree values, measured in quality index points, is shown in tables 3 and 4. As might be expected, grade A trees show the greatest variation in terms of Q.I. units for any given d.b.h.

Table 3.--Quality index values by site and size for log grades 1 and 2

Diameter inside bark (inches)	Log grade 1, with site index of--			Log grade 2, with site index of--		
	120	100	80	120	100	80
	Quality Index values					
12	108	100	92	84	81	78
14	108	100	92	86	83	79
16	108	100	92	88	85	81
18	108	100	92	90	86	83
20	108	100	92	92	88	85
22	108	100	92	94	90	87
24	108	100	92	95	92	88

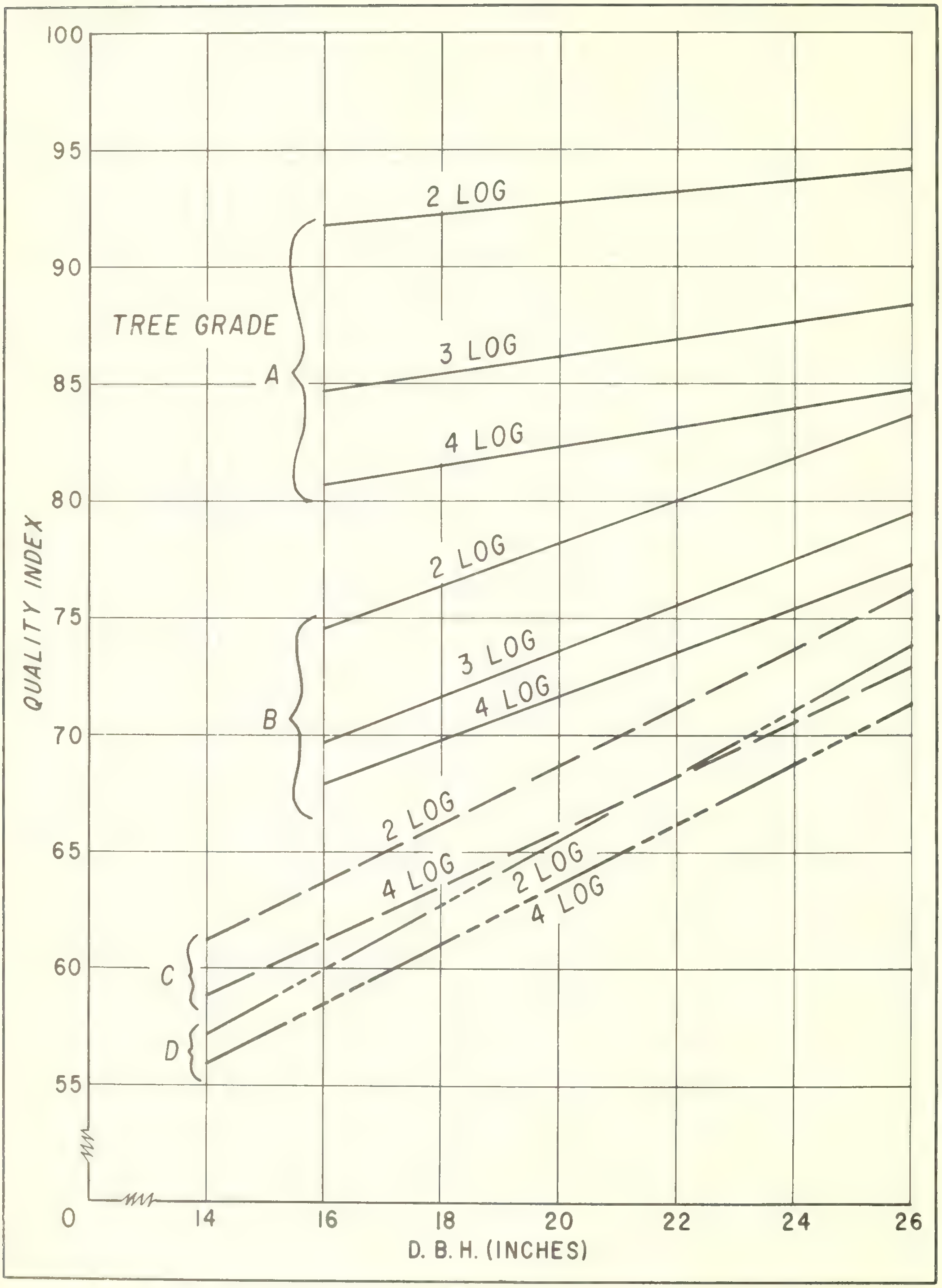

Figure 4.--Quality index values by grade and size.

Table 4. --Quality index values by site and size for tree grades A and B

Merchantable logs (number)	D. b. h.	Tree grade A, with site index of--			Tree grade B, with site index of--		
		120	100	80	120	100	80
	Inches	Quality Index values					
2 logs	16	98	92	86	76	75	72
	18	98	92	86	78	76	74
	20	99	93	87	80	78	76
	22	99	93	87	82	80	78
	24	100	94	87	84	82	80
	26	100	94	88	86	84	82
4 logs	16	84	81	77	69	68	66
	18	85	81	78	71	70	68
	20	86	82	78	73	72	70
	22	87	83	79	75	74	72
	24	87	84	80	76	75	74
	26	88	85	81	78	77	76

When site differences are expressed in dollars per M b.f. for the stumpage (conversion values) as shown in table 5, they are impressive; e.g., 20-inch grade A 2-log trees from site index 120, an excellent site, are worth \$52.50 per M, while those from site index 80, a fair site, are worth \$40 per M. Stumpage values for grades C and D are shown in table 6.

Table 5. --Stumpage values [1/] per M b.f. by site and size for tree grades A and B
(Dollars per M b.f.)

D. b. h. (inches)	2-log trees		4-log trees	
	Grade A	Grade B	Grade A	Grade B
SITE INDEX 120, (EXCELLENT)				
16	43.00	21.50	30.00	15.00
18	49.00	28.50	35.00	21.00
20	52.50	33.50	40.00	26.50
22	54.00	38.00	42.50	30.50
24	56.50	41.00	44.00	33.50
26	56.00	42.00	44.00	34.50
SITE INDEX 100, (GOOD)				
16	37.50	20.00	26.50	13.50
18	42.50	27.00	31.50	19.50
20	46.00	31.50	36.00	25.00
22	49.00	36.00	39.00	29.00
24	50.50	39.00	41.00	32.00
26	50.00	40.50	41.00	33.00
SITE INDEX 80, (FAIR)				
16	31.50	17.50	22.50	12.00
18	36.50	24.50	27.50	18.00
20	40.00	29.50	32.00	23.50
22	43.00	34.00	35.00	27.50
24	44.50	37.00	37.00	30.50
26	44.00	38.00	37.00	32.00

1/ Values based on No. 1 common lumber at \$115 per M b.f., less 12 percent for profit and risk, less logging and milling costs as shown by diagram in figures 5 and 6.

Table 6. --Stumpage values [1] per M b.f. by size for tree grades C and D

D.b.h. (inches)	2-log trees		4-log trees	
	Grade C	Grade D	Grade C	Grade D
	Dollars			
14	2.00	(2/)	(2/)	(2/)
16	10.00	6.00	7.50	4.50
18	17.00	13.00	14.00	11.50
20	23.00	19.00	19.00	17.00
22	28.00	24.00	25.00	22.00
24	31.00	27.50	27.50	25.50
26	32.00	28.00	28.00	26.00

1/ Values based on No. 1 common lumber at $115 per M b.f., less 12 percent for profit and risk, less logging and milling costs, as shown in figures 5 and 6.

2/ Negative values.

Earnings and Stumpage Values

In computing stumpage values, it is necessary to reduce wholesale lumber prices by a profit and risk margin and then deduct the average logging and milling costs, as shown in figures 5 and 6. The wholesale lumber prices for No. 1 common yellow-poplar were averaged at $115 per thousand board feet. This value was reduced by 12 percent for profit and risk. Tree Q.I. values by grade and size, shown in figure 4, were multiplied by the net lumber price of $101, and the results together with logging and milling costs are illustrated in figures 5 and 6. The difference between the costs and the net lumber price indicate stumpage values (equivalent to conversion values) per thousand board feet (tables 5 and 6).

As shown in table 5, stumpage values per M increase by tree size in fairly constant amounts. When 4-log trees increase in diameter from 16 to 26 inches d.b.h., the dollar value per M b.f. on 100-foot sites increases as follows: grade A trees increase 1.5 times in value, B's double, C's quadruple, and D's increase sixfold in value. Stumpage values as shown in tables 7 and 8 increase even faster over the same conditions: grade A's fivefold, B's eightfold, C's thirteen, and D's sixteenfold. Furthermore, a tree of a given log length will increase in value rapidly if it improves in grade as it grows in diameter. For example, a grade D tree now measuring 16 inches d.b.h. can improve to grade C with only 2 inches of diameter growth and will increase in value 50 to 100 percent (depending on the number of logs in the tree chosen for comparison). A grade C tree improving to a grade B with the same 2-inch-diameter growth will increase fourfold in dollar value. A corresponding increase in value will result if a tree remains in the same grade as it grows larger in diameter and taller in merchantable length. An even larger increase is possible if a tree increases in both grade and merchantable length while growing into a larger diameter class. If grade and length remain the same and the tree grows only in diameter, the owner will still earn 4 percent or more up to 26 inches d.b.h.

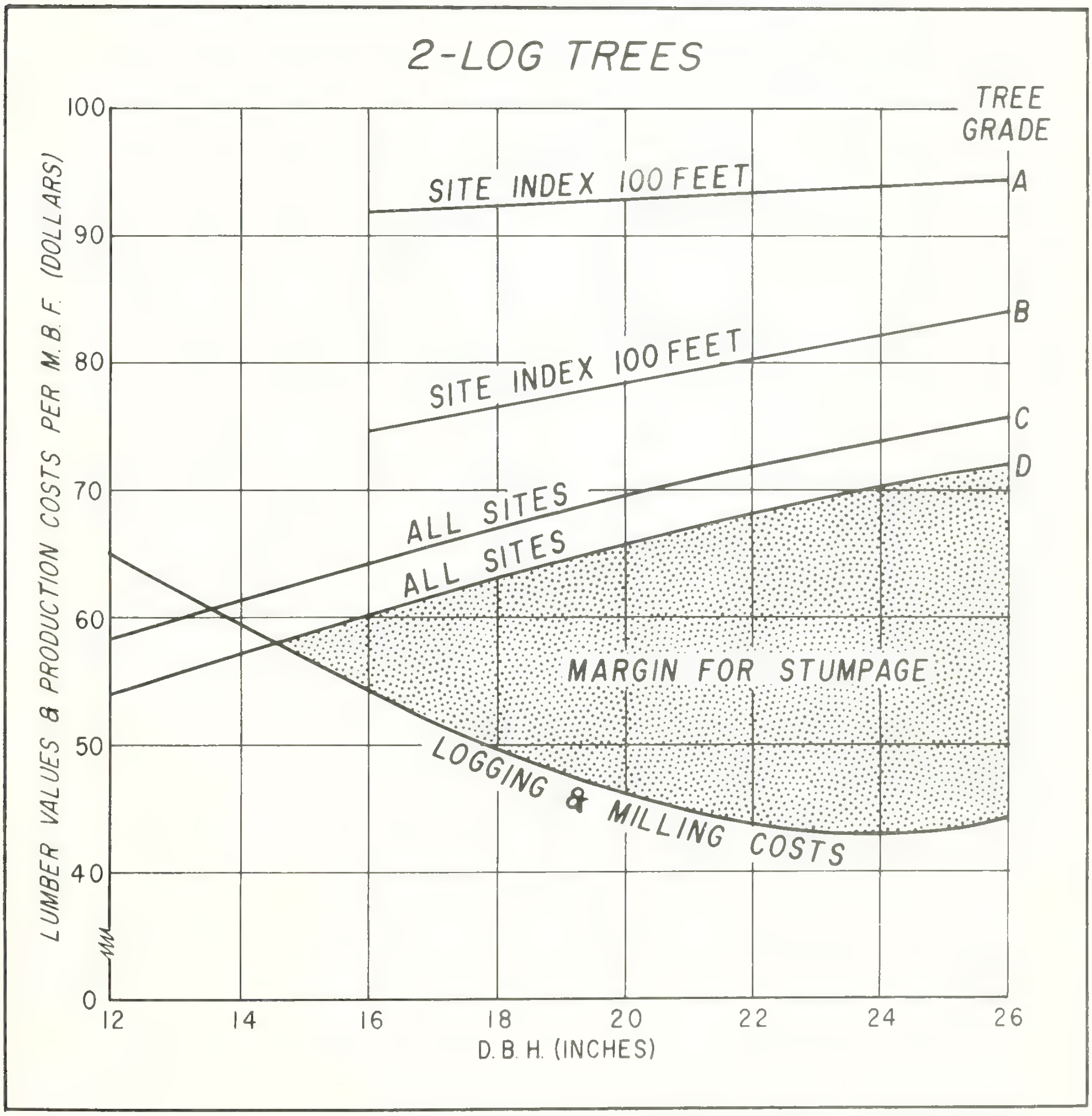

Figure 5. --Lumber values, logging costs, and stumpage margin per thousand board feet for 2-log trees. Based on quality index values for trees of different grades.

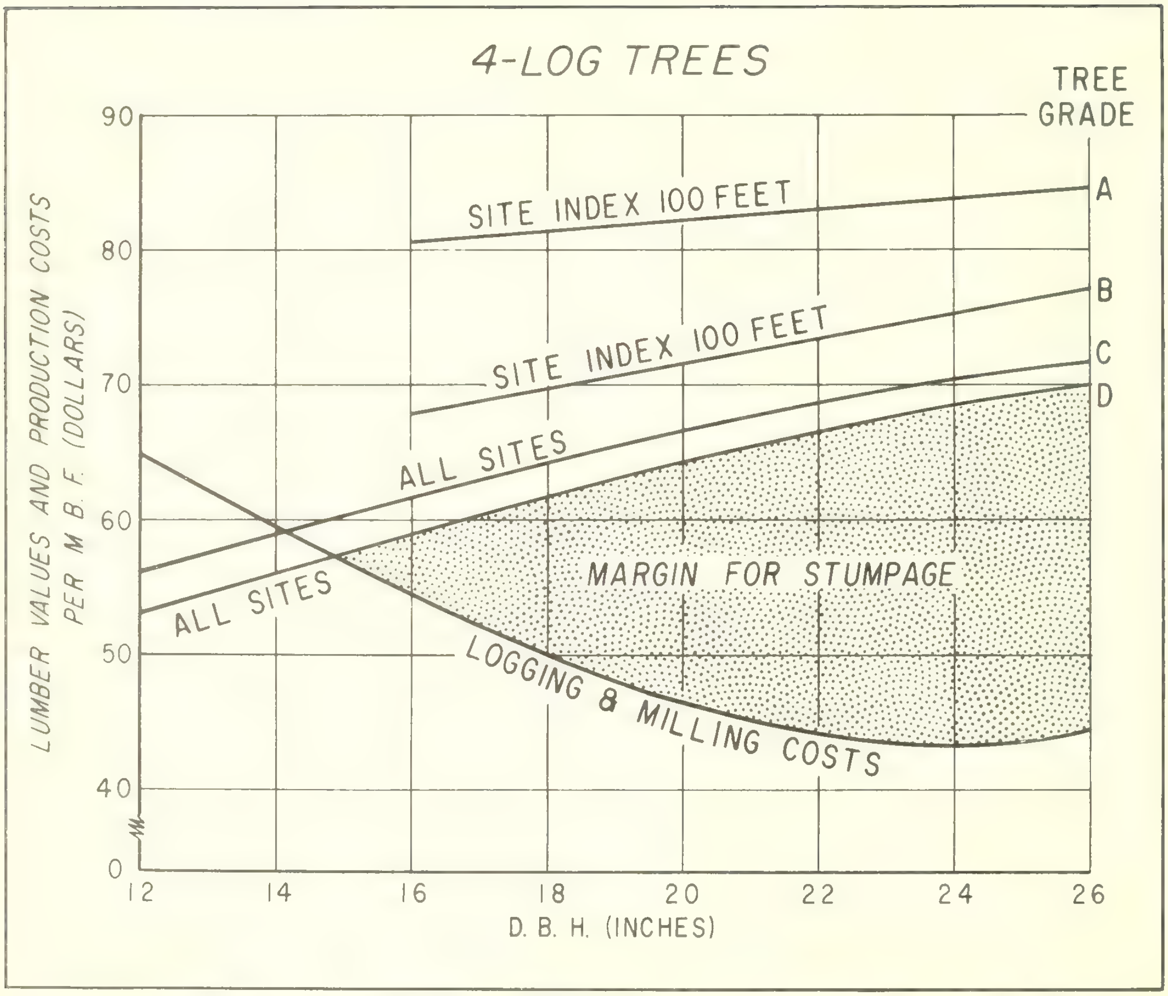

Figure 6. --Lumber values, logging costs, and stumpage margin per thousand board feet for 4-log trees. Based on quality index values for trees of different grades.

Table 7. --Curved stumpage values [1] by site and size for tree grades A and B
(Dollars per tree)

2-LOG TREES

Tree d. b. h. (and volume)	Site Index 120 (excellent)		Site Index 100 (good)		Site Index 80 (fair)	
	Tree grade A	Tree grade B	Tree grade A	Tree grade B	Tree grade A	Tree grade B
16 in. (185 bd. ft.)	8.00	4.00	7.00	3.50	5.75	3.25
18 in. (245 bd. ft.)	12.00	7.50	10.50	6.50	9.00	6.00
20 in. (315 bd. ft.)	16.50	10.50	15.00	10.00	13.00	9.50
22 in. (390 bd. ft.)	21.00	14.75	19.00	14.00	16.50	13.00
24 in. (470 bd. ft.)	26.00	19.00	23.50	18.50	21.00	17.00
26 in. (555 bd. ft.)	31.00	24.00	28.50	23.00	25.00	22.00
4-LOG TREES						
16 in. (290 bd. ft.)	8.50	4.00	7.50	3.75	6.25	3.50
18 in. (390 bd. ft.)	14.00	8.50	12.50	7.75	11.00	7.00
20 in. (510 bd. ft.)	20.50	13.50	18.50	12.50	16.00	12.00
22 in. (640 bd. ft.)	27.00	19.50	25.00	18.50	22.00	17.00
24 in. (780 bd. ft.)	34.00	25.50	32.00	24.50	28.50	23.00
26 in. (920 bd. ft.)	40.50	32.00	39.00	31.00	35.00	30.00

1/ Tree values are based on stumpage values shown in table 5. Computed values were plotted and curves were drawn from which the above values were read.

Table 8. --Stumpage values [1] by size for tree grades C and D

Tree d. b. h. (and volume 2/)	Average site index, 2-log trees		Tree d. b. h. (and volume 2/)	Average site index, 4-log trees	
	Tree grade C	Tree grade D		Tree grade C	Tree grade D
12 in. (105 bd. ft.)	(3/)	(3/)	12 in. (150 bd. ft.)	(3/)	(3/)
14 in. (135 bd. ft.)	0.35	0.20	14 in. (210 bd. ft.)	0.30	(3/)
16 in. (185 bd. ft.)	1.80	1.20	16 in. (290 bd. ft.)	2.10	1.50
18 in. (245 bd. ft.)	4.40	3.30	18 in. (390 bd. ft.)	5.70	4.60
20 in. (315 bd. ft.)	7.20	5.80	20 in. (510 bd. ft.)	10.00	8.40
22 in. (390 bd. ft.)	10.50	8.80	22 in. (640 bd. ft.)	15.00	13.00
24 in. (470 bd. ft.)	14.00	12.00	24 in. (780 bd. ft.)	20.50	18.50
26 in. (555 bd. ft.)	18.00	16.00	26 in. (920 bd. ft.)	26.50	24.50

1/ Tree values are based on stumpage values shown in table 5. Computed values were plotted and curves were drawn from which the above values were read.

2/ Curved volumes from table 12, Jesse H. Buell, "Outside-bark form class volume tables for some Southern Appalachian species," U. S. Forest Serv. Appalachian Forest Expt. Sta. Tech. Note 53, 1942.

3/ Negative values.

SUMMARY

This report summarizes the results of four separate studies of log and tree grade yields for second-growth yellow-poplar conducted in western North Carolina during 1955, 1956, and 1957. The study included 236 trees and 746 logs cut from a wide range of sites.

Log and tree quality indices were computed and are shown by size and grade. Lumber and stumpage values are also given. Stumpage values for second-growth yellow-poplar trees of all grades increase rapidly with increasing diameter up to about 24 inches diameter at breast height.

The study shows that the tree grading method gives a workable estimate of lumber values from second-growth yellow-poplars and can be used with confidence by timber cruisers and appraisers. Accuracy is improved by recognition of site differences, particularly in the case of grade A and B trees.

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Losses from Defect in Piedmont Hardwoods

by

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INTRODUCTION

During the past several decades, a large acreage of hardwoods has accumulated in the Piedmont on which most of the trees are either defective or regarded as undesirable. The older and larger of these trees are of poor quality because of uncontrolled fires, "high grading," careless logging, overgrazing, and a general lack of management. More recently, better fire control and changes in farmland use have increased the number of young unmanaged stands, adding further to the total volume of low-value hardwoods. Insects, diseases, and mechanical injuries are further factors contributing to the general decline in quality.

The need for research on hardwood quality has been intensified by the recent finding that the total volume of hardwoods in the Piedmont is increasing and now exceeds that of pine, and also by the increasing demand for hardwood products. Because of short supply, many of the small Piedmont hardwoods are being harvested now, and utilization is close. It is essential, therefore, to distinguish between defective or diseased and good-quality sound trees (Forest Service Hardwood Log Grades provide the best present measure of factory lumber quality), to find ways to use and profitably harvest the present defective trees for products other than lumber, and to learn how to obtain better quality in the crops of the future. Accomplishing these aims requires a knowledge of the prevalent defects of hardwoods in the Piedmont, and how they can be recognized in the various species. As a first step in obtaining the desired information, a woods survey and mill study were started in 1955. A preliminary report on part of the woods survey data was issued in 1958 as Southeastern Station Research Note 115, "Defect in Piedmont Hardwoods" (1).

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LITERATURE REVIEW

Many investigators have written of the poor condition of the hardwood component of forests in the South. Jemison (15) mentions "the defective low quality hardwood stands so prevalent today." Wahlenberg (24) listed as one of the two main causes of the lowered value of hardwood forests "... the policy of removing trees of the best species and quality first, continued without abatement to the present day." As a consequence, Harrar (8) recently wrote of hardwoods, "In general, log quality throughout the entire southeastern region is in steady decline. Virgin timber has been virtually depleted in many sections, and smaller, more highly defective, second-growth timber is being processed in ever increasing quantities." He further declares that "... rare indeed is the relatively small, second-growth tree-length log that does not exhibit one or more indicators of defect at some level along its bole."

A recently completed timber survey in central and northern Georgia revealed that 41 percent of the hardwood volume is unmerchantable because of cull (17).

Hepting (10, 11) has studied and reported the effects of fire scars and their relation to butt rot and extent of cull, both in southern hardwoods and Appalachian oaks. The progress of heart rot following fire in bottomland red oaks has been described by Toole and Furnival (23). Hepting et al. (13) studied the relation of external features to top rot in Appalachian oaks. Roth and Sleeth (20) reported the incidence of butt rot in unburned sprout oaks and suggested control measures.

Although fire protection and more careful logging have reduced losses from butt rot and other diseases in some stands the effects of diseases are still of major consideration in defect studies. "Timber Resources for America's Future" (12) states that diseases account for 45 percent of the growth impact [2/] caused by all destructive agents, and that heart rot and other stem diseases are the most important single group, causing 80 percent of the growth impact due to diseases.

The importance of insects as agents of defect was also stressed in "Timber Resources for America's Future." Insects kill more timber than diseases, and the reduction in growth and quality caused by these pests constitutes damage loss greater than that from outright killing. In an earlier publication, Snyder (21) described and classified insect-caused defects in timber according to extent and type of damage. Morris (19) is presently studying the reduction in grade of hardwood lumber due to trunk-boring insects in living trees.

Most of the information available on defect consists of descriptions of types, their identification, and effect upon grade, whether in a tree, log, or board. The handbook by Lockard, Putnam, and Carpenter (18) is the standard

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2/ Growth impact is defined as the total damage, including mortality and growth loss, due to destructive agents.

reference for description and evaluation of log defects in southern hardwoods. In the Piedmont, however, except in the case of fire, little research has been done to determine prevalence, specific causes, and relative importance of defects in different species under stand conditions, or to formulate control or management practices for minimizing defect.

It has not been intended that this work will define grading practices or will prescribe final forest management measures for reducing degrade in the future. The purpose of the study is limited to providing basic information on incidence, extent and causes of, or possible influences contributing to defect in the many hardwoods now growing to merchantable size in the Piedmont.

PLAN OF WORK

The formal investigation was preceded by a small-scale exploratory study in nearby forests to observe the more obvious indicators of defect, and to develop survey and measurement techniques. Identification of many of the defects and their indicators was facilitated by reference to the handbook "Log Defects in Southern Hardwoods," by Lockard, Putnam, and Carpenter (18).

As part of the exploratory study, short, small-diameter bolts (3 feet x 9 inches maximum) exhibiting various types of defect or unfamiliar surface characteristics were collected and sectioned. The extent of defect beneath indicators was measured, and photographs were made showing indicators in slabs and associated defect in successive boards (see pages 21 and 22). Also, a number of diseased trees were sectioned in the woods to determine extent of decay beneath cankers and sporophores.

The exploratory work was followed by the major investigation, which was divided into two parts: a woods survey, and a mill study, carried out in that order. Working in the woods first enabled the surveyor to recognize types of disease and cull by association with their identifying sporophores. These and other small surface indicators would be lost or no longer recognizable had the logs been skidded and hauled to the mill. Hay and Wootten (9), for example, experienced difficulty in examining log faces which had been covered with mud during logging. This sequence of procedure also permitted the investigator to see and evaluate all evident defects including those in cull, which normally would be left in the woods either as species not logged or as cull sections.

Original plans for the mill study were to number, examine, and record defects on 16-foot butt lengths of trees to be cut at logging operations, using the same procedure as in the woods survey. The numbered logs were to be followed to the mill for detailed internal examination. Refinement of procedure during the woods survey was regarded to be desirable before undertaking studies at mills. Limited resources available, however, later forced a revision of the mill study plans.

THE WOODS SURVEY

Methods

The first phase of the study, an extensive woods survey of the Piedmont of North and South Carolina and Georgia, provided information on types and prevalence of defect in relation to species, site, and other influences, and in relation to various individual tree characteristics. Line-transect locations, hereinafter referred to as plots, were selected by a modified systematic sampling method. The number of plots selected per state was proportioned to the area of Piedmont plateau within each state. Thus, 33 plots were selected in North Carolina, 21 in South Carolina, and 46 in Georgia (fig. 1). Eleven of the plots in northwest Georgia, although not in the designated Piedmont land type, were similar to those in the Piedmont plots, and are consequently included in this report.

At each plot location, a compass line was started at the first tree selected well within the stand, and so extended as to stay within an area of given site characteristics. The first 10 hardwood trees 8.0 inches (diameter breast high) or larger that were either along the line or had branches extending over the line were measured. The area of plots was not considered important for analysis of the data in this study.

Plot descriptions included the following: state, county, date, plot number, line direction, aspect, basal area, and site description which took in terrain drainage and general forest and soil type. The approximate age of each stand was obtained from an increment boring of a dominant, average-sized tree of the prevalent species.

The following data were recorded for each tree: species, d. b. h., diameter estimate at upper merchantable limit of stem,[3/] last 10-year radial increment, location of defects or defect indicators on next-poorest face of butt log[4/] (drawn to scale on data sheet), cause of defect when evident, dimensions of cull sections that could be determined, sweep or crook measurement for butt log and for full merchantable length, and compass orientation of the four graded faces of the butt log.

3/ From forest survey rule of thumb: the point at which the diameter of a limb or the sum of the diameters of several limbs equals one third the diameter of the tree at that point; or, the point at which the stem is 4 inches in diameter.

4/ The next-poorest face of the butt log was determined by examining all four faces and selecting in the manner described for hardwood log grading by the U. S. Forest Products Laboratory (6). The poorest of the three best faces (next-to-poorest of all four faces) of each sample tree was chosen for detailed examination.

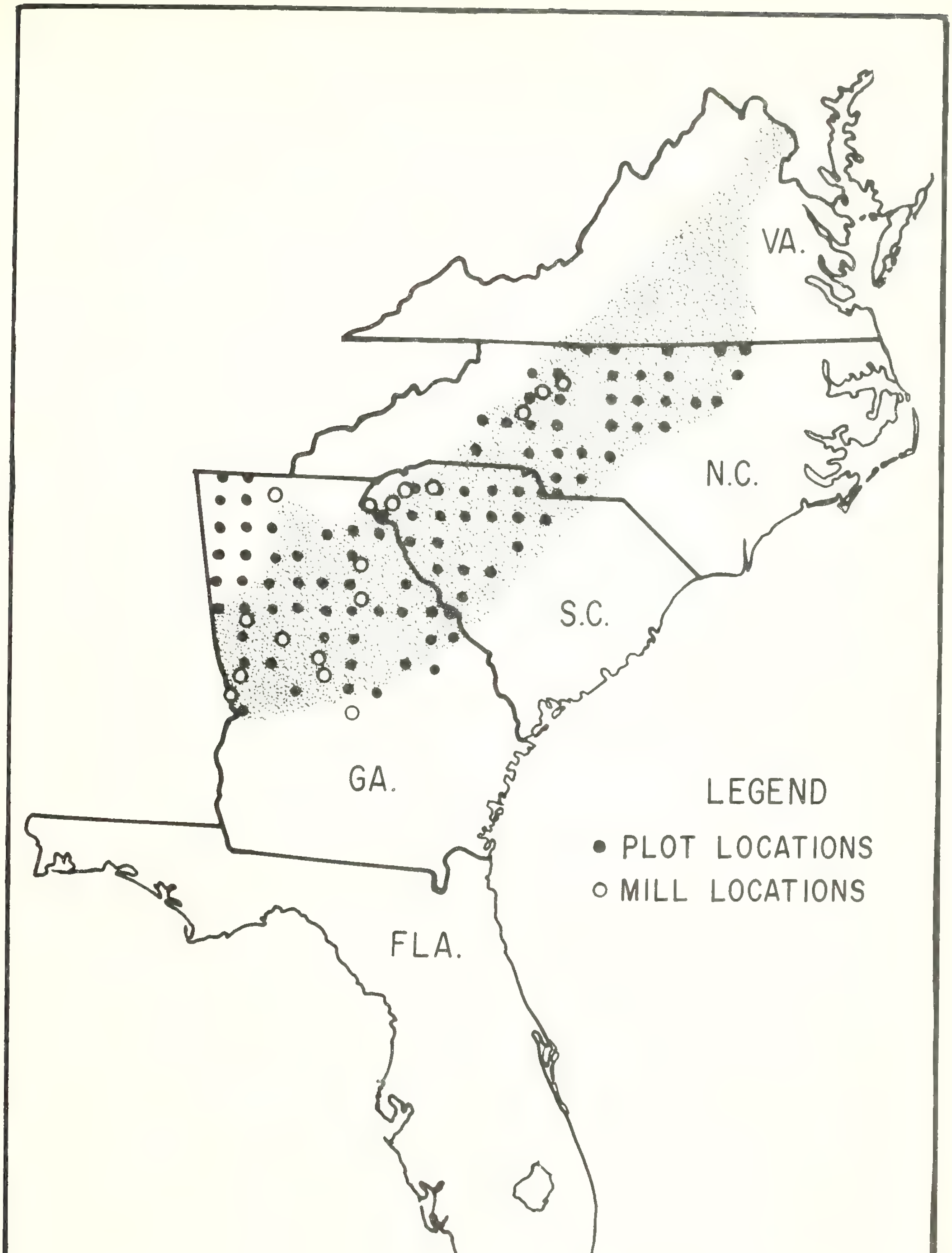


Figure 1.--Location of line-transect plots and mills surveyed. The shaded area represents the Piedmont.

A method of tree quality measurement was sought that would allow rapid assessment of standing trees in the extensive area to be surveyed. It was desired to measure trees so that an estimate could be obtained of the quality of lumber that might be harvested from the sample trees. Thus, the average of the estimates might be interpreted as representative of the general quality of hardwoods in present Piedmont stands. The recording of defects on the next-to-poorest face of the butt log, and the use of the concept of "clear-cuttings" follow Campbell (2, 4) in his tree-grade method of quality measurements. This method, excepting end defects, is based upon factory log grades established by the Forest Products Laboratory (6), and upon the known tendency for the upper logs in a tree to be of lower quality than those next below them. Thus, by grading the butt log of a standing tree, grades of the other logs may be estimated. A recent study of black oaks in southern Illinois has shown that the grade of the best 10-foot section of the butt 16-foot log is a good indicator of the value of the factory grade lumber contained in the whole tree (14). The recording of defects as used in the tree grading method offered a workable field procedure for obtaining the desired information, and for a later analysis and expression of the comparative net effects of different defects upon quality. The small diameters of the majority of the randomly selected sample trees excluded the possibility of using the tree grading system in its strictest sense as a basis of comparison in analyzing the data from the woods survey.

The following is a listing of possible degraders for which trees were examined during this study. It was compiled by borrowing freely from log and surface abnormalities listed by Lockard, Putnam, and Carpenter (18). All types of birdpeck were recorded; for appraising damage, distinction was made between light and heavy attack and whether fresh or occluded, as set forth by Lockard et al. Knots were measured at the knot collar flush with bark surface.

1. Canker
2. Conk
3. Rotten branch
4. Unsound knot
5. Butt rot
6. Heart rot
7. Birdpeck
8. Dormant buds; epicormic, adventitious branches
9. Small knot $1\frac{1}{2}$ inches
10. Medium knot $1\frac{1}{2}$ to 3 inches
11. Large knot 3 inches up
12. Small hole, misc. $\frac{1}{4}$ to $\frac{1}{2}$ inch
13. Medium hole, misc. $\frac{1}{2}$ to 1 inch
14. Large hole, misc. 1 inch up
15. Small hole or scar, insect $\frac{1}{16}$ to $\frac{1}{8}$ inch
16. Medium hole or scar, insect $\frac{1}{8}$ to $\frac{1}{4}$ inch
17. Large hole or scar, insect $\frac{1}{4}$ inch up
18. Burl
19. Butt bulge
20. Stem bulge
21. Bump
22. Bark distortion
23. Butt scar
24. Stem scar
25. Seam
26. Overgrowth
27. Sweep
28. Crook
29. Fork

Definitions of plot and tree characteristics used as bases of measurement are as follows:

Site.--Four general sites were recognized: ridge, slope, cove, and lowland or bottom. On slope sites, survey lines were run at midslope level. The 100 randomly selected plots were distributed in the four classes as follows: ridge 10, slope 47, cove 12, and lowland or bottom 31.

Aspect.--Five variations in aspect were recognized: flat, north, east, south, and west. By aspect, the plot distribution was as follows: flat 28, north 31, east 18, south 10, and west 13.

Basal area.--Basal area was measured with a wedge prism from a point on the plot line where density was estimated as average in the plot and immediate surrounding stand. The observed basal area range was divided into the following four classes: 50 to 90, 100 to 140, 150 to 190, and 200 to 240 square feet per acre.

Species.--Forty different species were encountered on the plots. Since the plots and trees were chosen at random, the number of each species reflects its relative abundance in diameter classes 8.0 inches d. b. h. and larger. White oaks were the most frequently encountered species group (table 1).

Table 1.--Tree species and frequency of occurrence on all plots

Species or species group	Total	Species or species group	Total
	Number		Number
White oaks	274	Sycamore	5
Red oaks	261	Hackberry	3
Sweetgum	127	Redbay	3
Hickories	99	Cottonwood	2
Yellow-poplar	82	White ash	2
Blackgum	53	Black walnut	2
Red maple	28	Holly	1
Elms	26	Silver maple	1
Green ash	12	Sourwood	1
River birch	10	American hornbean	1
Beech	7		

Diameter classes.--The range in diameters was divided into classes to conform to the minimum requirements in the tree-grading system. The percentages in each of the classes were: 8.0 to 9.9 inches, 29 percent; 10.0 to 11.9 inches, 27 percent; 12.0 to 15.9 inches, 31 percent; and 16.0 through 29.0 inches, 13 percent.

Crown classes.--Standard crown class designations were employed: (1) suppressed, (2) intermediate, (3) codominant, and (4) dominant.

Vigor classes.--In this study, vigor is expressed as a measurement of the past 10-year radial increment. Classes are based upon those recognized by Cummings and Zarger (5):

Low--radial increment less than 0.6 inch during past 10 years.
Medium--radial increment 0.6 to 1.3 inches during past 10 years.
High--radial increment 1.4 inches or more during past 10 years.

Sweep and crook. --Measurable sweep in the 16-foot butt logs (greater than 2 inches) and crook cull percentages were calculated from the formulae established by Grosenbaugh (7). Classes of these two cull factors combined were based upon the maximum percentages allowed in the log grades. These were: (1) 0 to 15 percent, (2) 16 to 30 percent, (3) 31 to 50 percent, and (4) 51 percent or higher.

Compass orientation of graded faces. --After the four faces of each butt log had been graded, the general cardinal direction of each was recorded.

The purpose of these observations was to determine whether any correlation exists between defect occurrence on a face and the compass orientation of the face. Plot aspect was also considered in this relationship.

Results

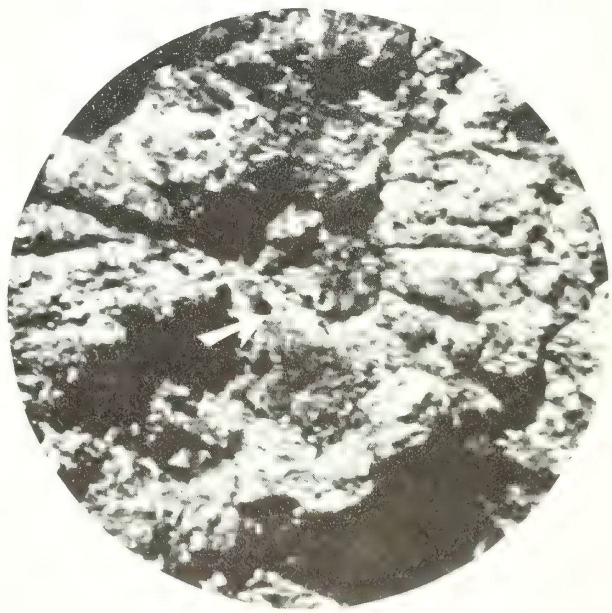
The average diameter of the sampled trees was 12.2 inches (range, 8.0 to 29.0), which gives an indication of lumber quality to be expected. Campbell (3) has stated that tree size is the primary factor in tree grading, and further that a tree must ordinarily be at least 16 inches d. b. h. before it can be considered for either of the upper two grades. Of the trees measured, only 13 percent were 16 inches in diameter or larger.

Most of the trees examined exhibited several types of defect. Figures 2 through 10 illustrate the principal defects and diseases encountered.

Since the sample trees in the woods survey were too small to permit use of tree grades in expressing results from analysis of the data, some other measurement was sought that would show the relative spacing of defects on the bole. Common practice in most hardwood industries limits the minimum length of clear lumber used to 2 feet. This length was therefore arbitrarily chosen as the basis of measurement to express the individual and total effect of defects upon quality. The results were not intended to be representative of actual log grades.

F-489547

Figure 2.--Epicormic and adventitious branching in red maple. An example of the severe quality-limiting effect of this common defect.



F-489548

Figure 3.--Insect borer scar in scarlet oak. Note typical "puckered," swollen appearance of wound tissue in bark.

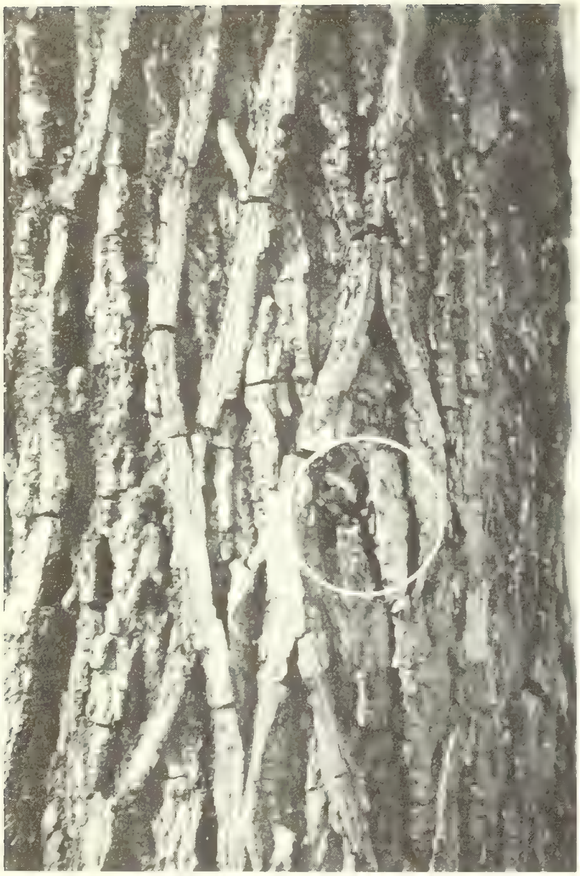


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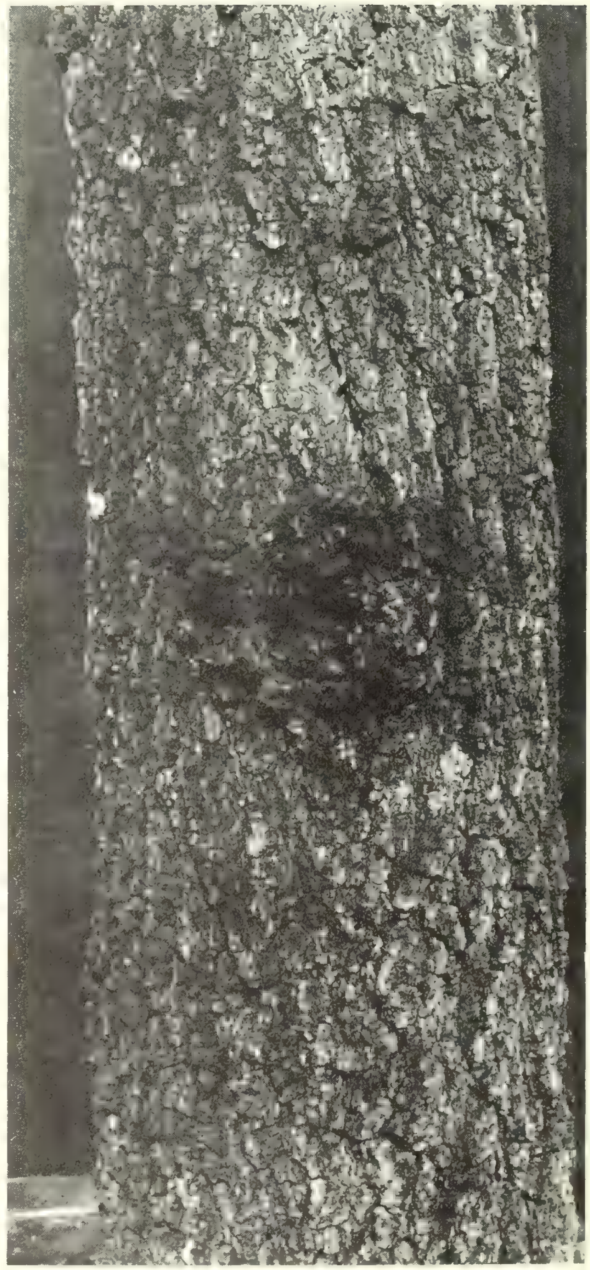
Figure 4.--Insect entry scar in pignut hickory. "Puckered" callus tissue also evident.

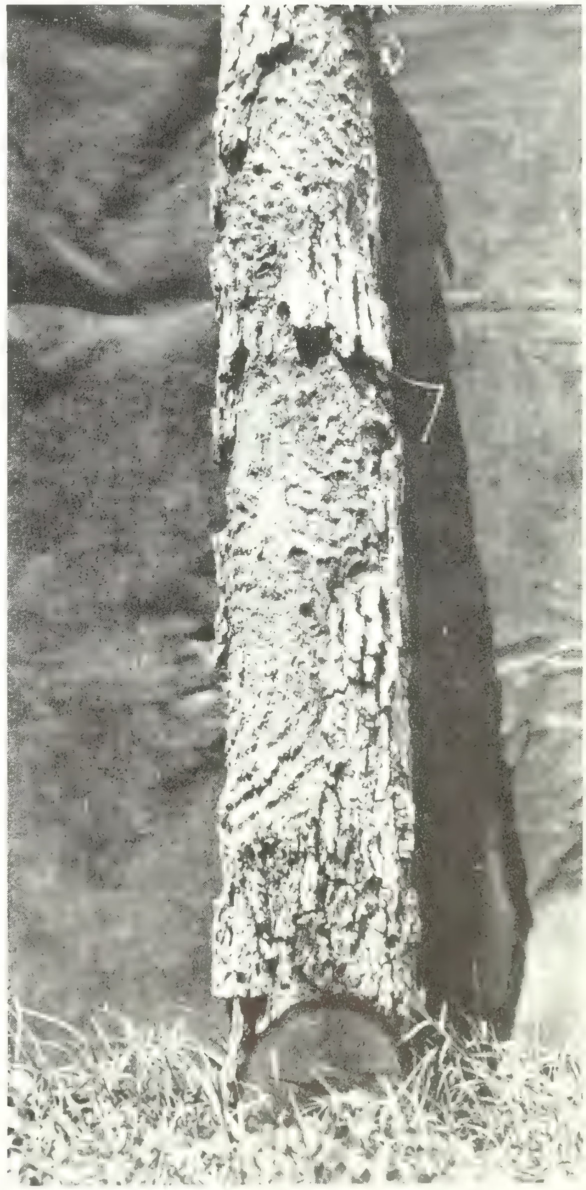


F-489550

Figure 5.--Poria spiculosa canker on 12-inch southern red oak.

F-489551

Figure 6.--Canker and sporophore on 9-inch black oak, produced by Polyporus hispidus.

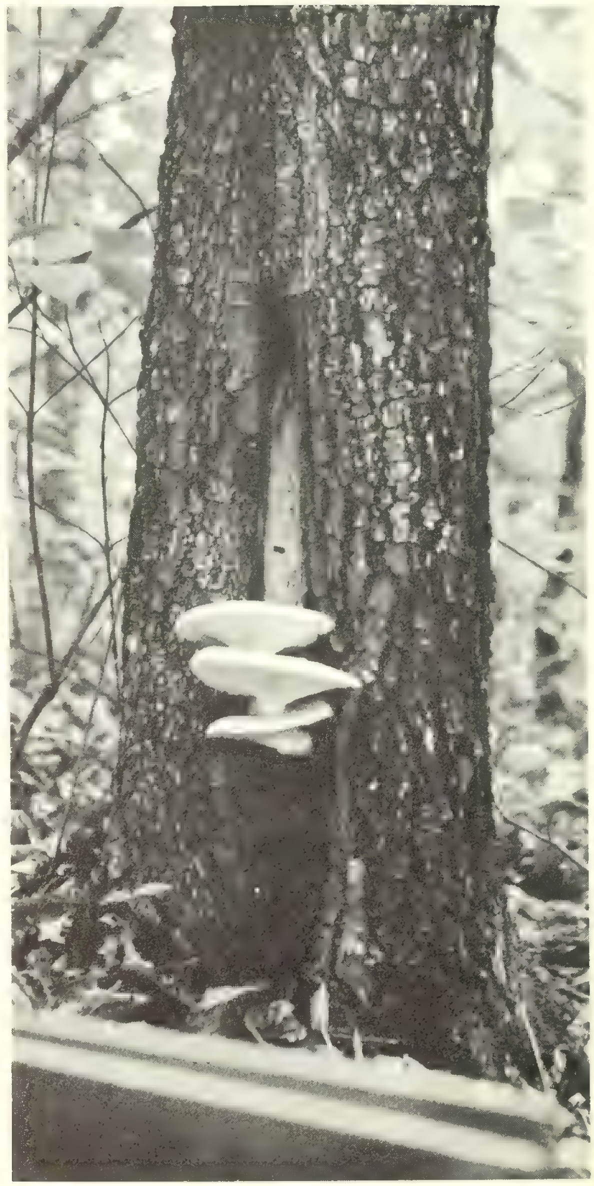


F-489552

Figure 7.--Cankered 5-inch post oak. Canker is of the type caused by Endothia parasitica (chestnut-blight fungus).

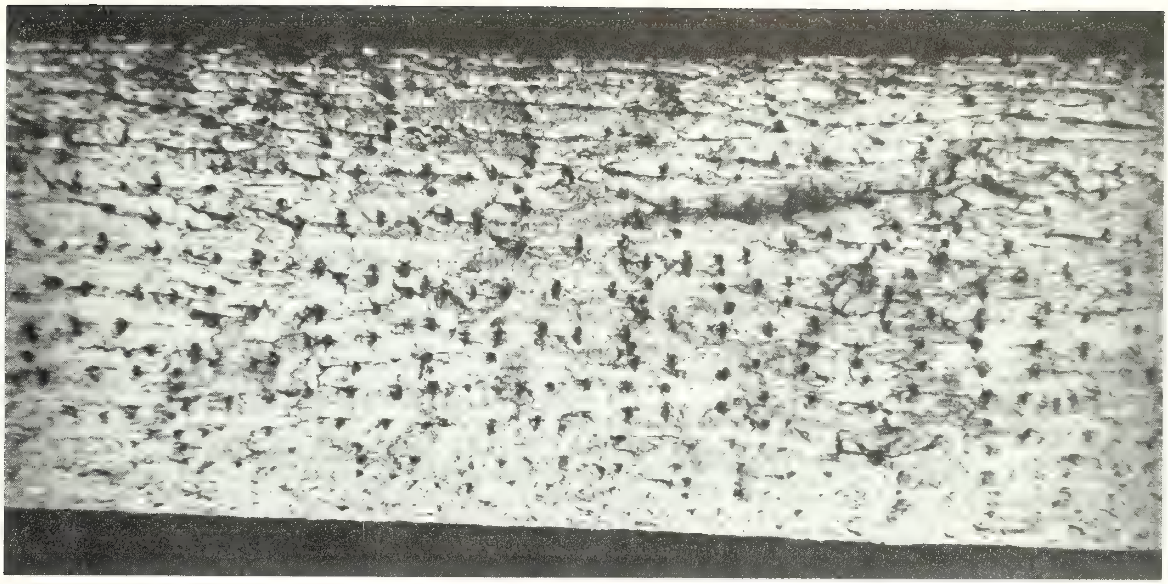
F-489553

Figure 8.--Fomes everhartii canker and sporophores on 10-inch water oak.



F-489554

Figure 9.--Open fire scar on black oak with Pleurotus ostreatus fruiting upon exposed rotted heartwood. Insect borer holes also evident.



F-489555

Figure 10.--Heavy birdpeck defect on 12-inch yellow-poplar.

To obtain the total effect of all defects upon quality, the diagram of each next-to-poorest face was examined and measured for 2-foot lengths or "cuttings" that would be free of defect or "clear" extending from the first board beneath the slab to the heart. The number of clear cuttings was expressed as a percent of total log length. Table 2 shows results from these measurements of 972 trees surveyed, expressed as the actual percent clear in 2-foot cuttings, considering all defects present on the measured face. The extremely small percentage of clear 2-foot cuttings obtainable emphasizes the low quality of present Piedmont hardwoods of the sizes studied.

Table 2. --Quality measurement, by 2-foot cuttings in butt logs of standing trees on next-to-poorest face 1/

Species or species group	Possible 2-foot cuttings	Clear 2-foot cuttings	
	Number	Number	Percent
White oaks	2,192	3	0.14
Red oaks	2,088	4	.19
Sweetgum	1,016	18	1.77
Hickories	792	16	2.02
Yellow-poplar	656	15	2.29
Blackgum	424	0	.00
Red maple	224	5	2.23
Elms	208	15	7.21
Green ash	96	0	.00
River birch	80	0	.00

1/ These data, which are not representative of log grades, show only the relative clearness of the surface of the listed species, on a basis of the entire list of possible degraders listed on page 6. The low percentages shown are mainly the result of the high frequency and scattered spacing of epicormic and adventitious branches on the grading face of the predominantly small-sized trees presently found in the Piedmont.

The cuttings referred to are 2-foot lengths that would be clear or free of all defect. These lengths are the full width of the face.

The same measurement procedure was used to obtain the separate effect of each type of defect. The actual and hypothetical 2-foot clear lengths obtainable were measured between each type of defect. Instead of expressing the results as percent clear, however, the complementary percentages were used to express the effects as percent reduction or loss of clear 2-foot cuttings. The individual effects of the principal quality-limiting defects, other than stem disease and other cull influences, are shown in table 3. In some species the small number of trees measured means, of course, that indications of their defects or quality are questionable. The greatest reduction in clear 2-foot cuttings for all species is shown to be due to small knots. For epicormic and adventitious branching, the least loss occurred in hickories and the greatest in red maples. Insect damage, the second most common defect, was mostly caused by various trunk borers. Approximately three-quarters of the loss from these defects resulted from small and medium-sized insect holes. The oaks exhibited the highest percentage reduction in clear cuttings; yellow-poplar the lowest.

Table 3. --Individual effect of 8 quality-limiting defects in butt logs of standing trees expressed as mean percent reduction in 2-foot clear cuttings on next-to-poorest face 1/

Defects	White oaks	Red oaks	Sweetgum	Hickories	Yellow-poplar	Blackgum	Red maple
				Percent			
Epicormic and adventitious branching 2/	39	51	54	31	59	39	60
Small knots 2/	86	85	73	85	71	88	67
Medium and large knots	16	16	21	17	16	17	16
Small insect holes	12	30	25	12	0	25	37
Medium insect holes	21	28	21	20	19	19	18
Large insect holes	12	20	12	24	12	9	0
Butt and fire scar	16	26	23	15	32	19	25
Stem scar	15	30	29	20	38	19	12

1/ Does not include stem disease, sweep or crook. Measurement of the reduction in clear length due to each type of defect was made independently of any other type present on the face.

2/ The high percentages listed here are again a reflection of the high number and naturally scattered occurrence of these defects on the small-sized trees presently found in the Piedmont. After the trees reach merchantable size and are harvested, many of these indicated defects will be buried beneath some clear wood or lost in the sawn slabs.

Incidence of stem disease is presented in figure 11. The higher percentages of cankers in red oaks and hickories were mainly the result of infection by Poria spiculosa.

The principal identified fungi causing cankers and heart rot in red oaks were: Poria spiculosa, in 7.7 percent of the trees; Polyporus hispidus, 3.4 percent; Fomes everhartii, 1.9 percent. Only 0.4 percent of the white oaks were infected by Polyporus hispidus. Cankers of the type caused by Endothia parasitica were found in 14.3 percent of the post oaks. Of the hickories, 8.1 percent were infected with Poria spiculosa. The relative occurrence of Poria spiculosa and Polyporus hispidus in the species affected is shown in table 4.

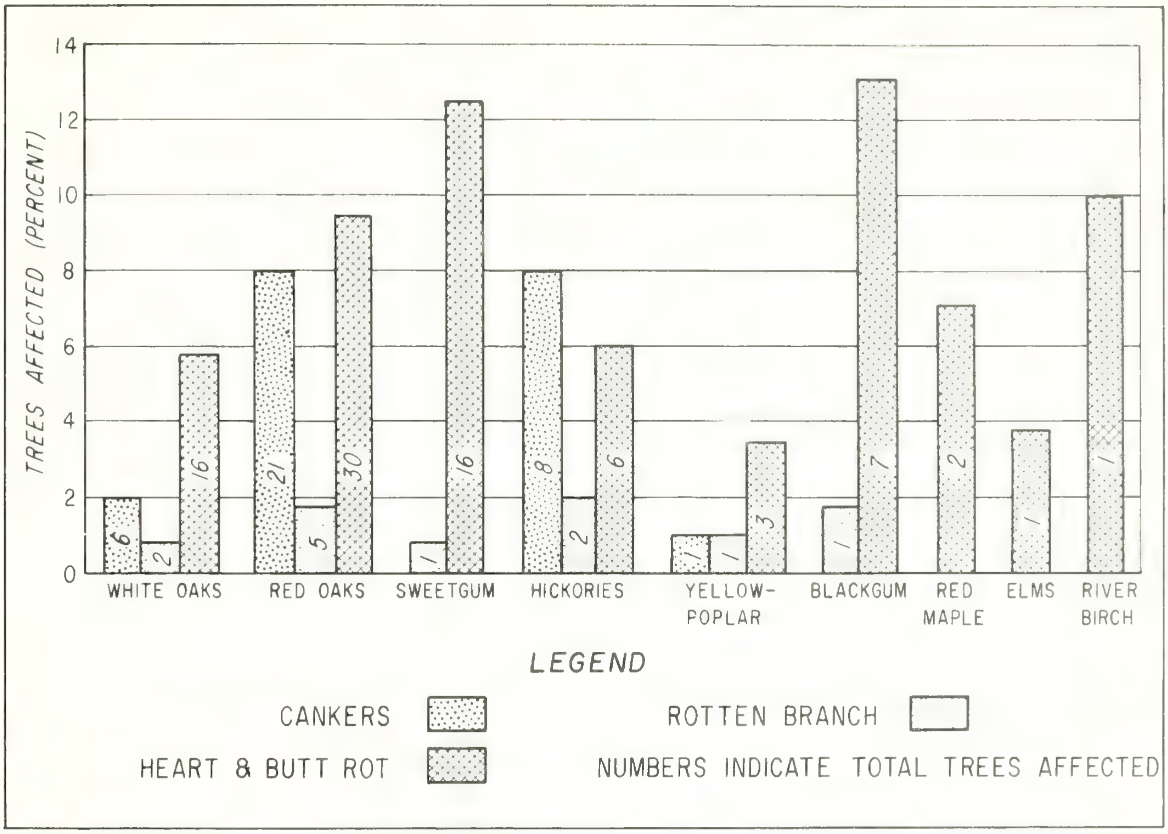


Figure 11.--Incidence of stem disease in butt log by species.

Of 1,000 butt logs measured, 359 had measurable sweep and crook. The average cull percent for butt logs as a result of these 2 defects among 10 species or species groups is illustrated in figure 12. In order of severity, the highest percent sweep or crook was found in green ash, red maple, and blackgum. A further breakdown of the total affected logs into the four classes or intensities of sweep and crook used in tree grading is shown in figure 13. As the intensity of the defect increased, there was a decrease in percent of butt logs affected.

Table 4.--Occurrence of Poria spiculosa and Polyporus hispidus

Fungus	Species affected						
	Water oak	Black oak	Southern red oak	Scarlet oak	White oak	Pignut hickory	Mockernut hickory
	Percentage of trees attacked						
Poria spiculosa	23	7	8	0	0	8	13
Polyporus hispidus	8	3	0	5	0.5	0	0

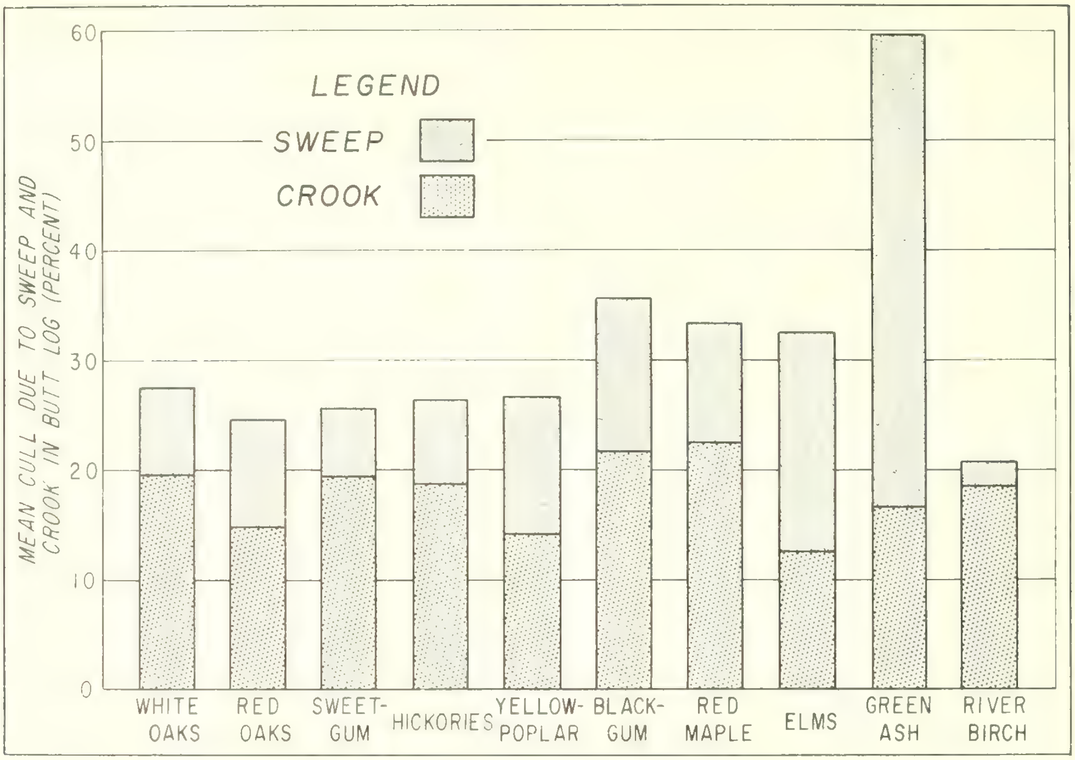


Figure 12.--Average sweep or crook in butt log of 10 major species or species groups. Percentages calculated from formulae established by Grosenbaugh (6).

All types of birdpeck were recorded in order to learn the general incidence and comparative occurrence in the different species. Since affected trees may be re-attacked, the general information, although not accurately measuring degrade, may provide a rough estimate of trees that will be seriously affected in the merchantable crop. Intensity and severity of the damage were recorded for purposes of measuring the degrade caused by the defect. Birdpeck was found in 14 percent of the trees examined. Of the affected trees, 96 percent would not be seriously damaged below the slab, but 4 percent would be degraded because of occluded birdpeck holes. The principal species affected and the percentage of trees showing birdpeck are as follows: Hickories, 44 percent; red maple, 42 percent; elms, 30 percent; white oaks, 14 percent; yellow-poplar, 13 percent; and sweetgum, 8 percent.

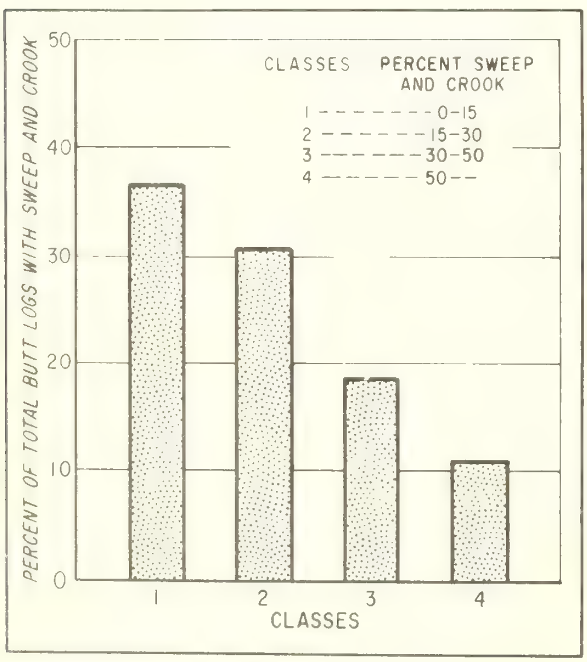


Figure 13.--Distribution of all butt logs affected by sweep or crook.

Fire scars were noted on 12 percent of all plot trees. Practically all fire-scarred trees were located in plots adjacent to a field, the fires apparently having spread into the woods during field burns. A breakdown of fire-scarred trees by state showed Georgia with 17 percent, North Carolina 9 percent, and South Carolina 7 percent. Fire intensity appeared to have been higher in Georgia than in the other states surveyed. Within plots having a fire history in Georgia, 27 percent of the trees were injured; in North Carolina, 19 percent; and in South Carolina, 15 percent.

Defects and Their Correlation with Other Factors

Knottiness. --The prevalence of epicormic and adventitious branching and knots was higher than for any other defect. Their scattered distribution along the bole is the cause of their great effect in decreasing quality. Based upon clear 2-foot cuttings, losses caused by these defects range from 12 to 99 percent, depending upon the tree species and size of knot. It should again be emphasized, however, that many of these defects are lost in slabs.

Intensive measurements were made of the independent influences of site, aspect, diameter class, crown class, vigor, and basal area upon percent loss due to epicormic and adventitious branching. Of these, only diameter, crown class, site, and basal area showed significant effects. These relationships are presented in figure 14. Losses due to epicormic and adventitious branching are highest in stands of high basal area, and in cove and lowland or bottom sites. The results concerning basal area are not correlated with tree size. This is shown by a comparison of the diameter distribution percentages for each basal area class listed in table 5.

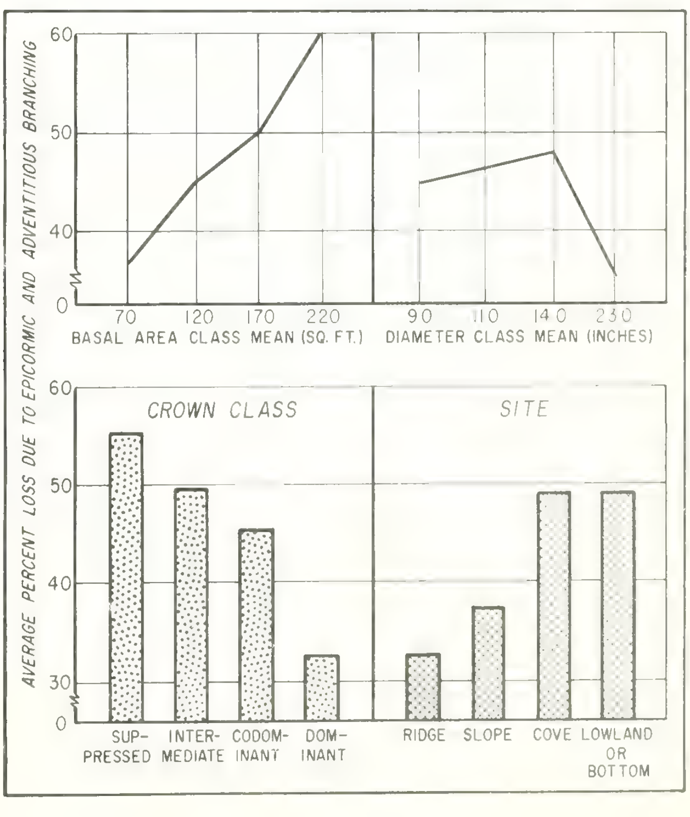


Figure 14.--Correlation between basal area, diameter class, crown class, and site, and loss of 2-foot clear cuttings due to epicormic and adventitious branching.

Table 5. --Distribution of sample tree sizes in the basal area classes

Diameter class mean (inches)	Basal area class			
	50 to 90 square feet	100 to 140 square feet	150 to 190 square feet	200 to 240 square feet
	- - - - - - - - - - -	Percent	- - - - - - - - - - -	
9.0	27.4	31.5	31.9	32.5
11.0	20.9	29.8	26.9	22.5
14.0	41.2	27.2	30.8	30.0
23.0	10.5	11.5	10.4	15.0

The increasing losses due to these branching defects, which are shown in a comparison between the crown classes progressing from dominant through codominant, intermediate and suppressed, suggest a possible relationship between this trend and the phenomenon known as apical dominance. This term is defined as the suppression of lateral bud growth by the terminal bud. Profuse branching along the stem after removal of the terminal is a trait exhibited by trees and many other plants. Thimann and Skoog (22) showed with pea plants that the effect of the terminal bud in inhibiting lateral bud development is due to a growth regulating substance produced in the terminal bud. Quite possibly in a suppressed or crowded tree crown, apical dominance has been lost because of a disturbance of terminal-bud auxin production, and lateral bud development is no longer strongly inhibited.

The lowest losses are in dominant trees or those having a d. b. h. of 16 inches and larger. Similar findings concerning crown development and epicormic branching in white oak have been recently reported by Krajicek (16). The same significant trends were obtained when species, mean diameter, and site were held constant, with basal area varied, and also when species, mean diameter, and basal area were held constant, with site varied.

Insect damage. --Analyses were made of quality loss due to insect defects in relation to each of the diameter, site, basal area, and vigor classes. Of these, site, basal area, and vigor influenced the severity of loss, as shown in figure 15. Losses due to insect defects were lowest in cove sites, in stands of high basal area, and in trees of high vigor. The range in tree diameters in this study was not broad enough to show the relationship reported by Hay and Wootten (9), that quality loss caused by insect damage increases as diameter increases.

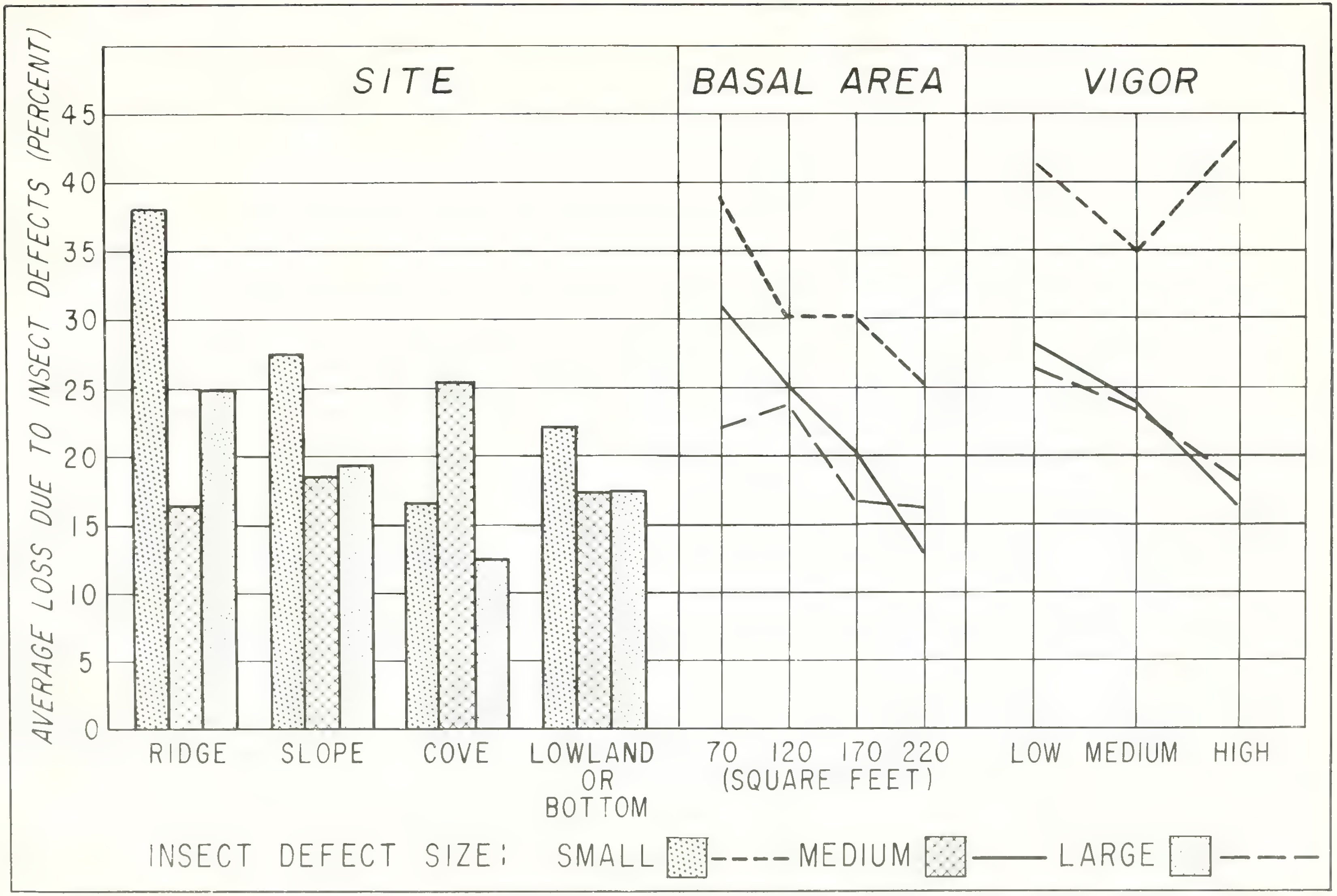


Figure 15.--Loss of 2-foot clear cuttings due to insect defects, by site, basal area, and tree vigor.

Stem disease.--No correlation was found between incidence of stem disease and variable site or other influences.

Influence of Face Direction and Slope Aspect on Face Grade

Analysis of the effects of plot aspect and compass direction of the two poorest faces reveals that for all aspects, 66 percent of the next-to-poorest faces and 67 percent of the poorest faces occurred on either the west or south sides of the trees. Further, the highest percentage (44 percent) of the poorest faces was found on the flats and on the south sides of the trees, while the highest percentage (also 44 percent) of next-to-poorest faces occurred on the south sides of trees growing on west aspects. These data reflect the high prevalence of epicormic and adventitious branching and small knots on the warmer faces.

Examination of losses due to insect defects in relation to compass direction of affected faces showed no significant differences.

Influence of Site upon Tree Vigor

When we examined the relation between vigor of all plot trees and site, we found that medium-vigor trees comprised the majority on ridge, slope, cove, and bottomland sites (fig. 16). There was a greater proportion of low-vigor trees on cove sites than on bottomlands. On the other hand, the percentage of high-vigor trees on bottomlands was more than twice that on cove sites. No relation was found between stand density and vigor-class percentage.

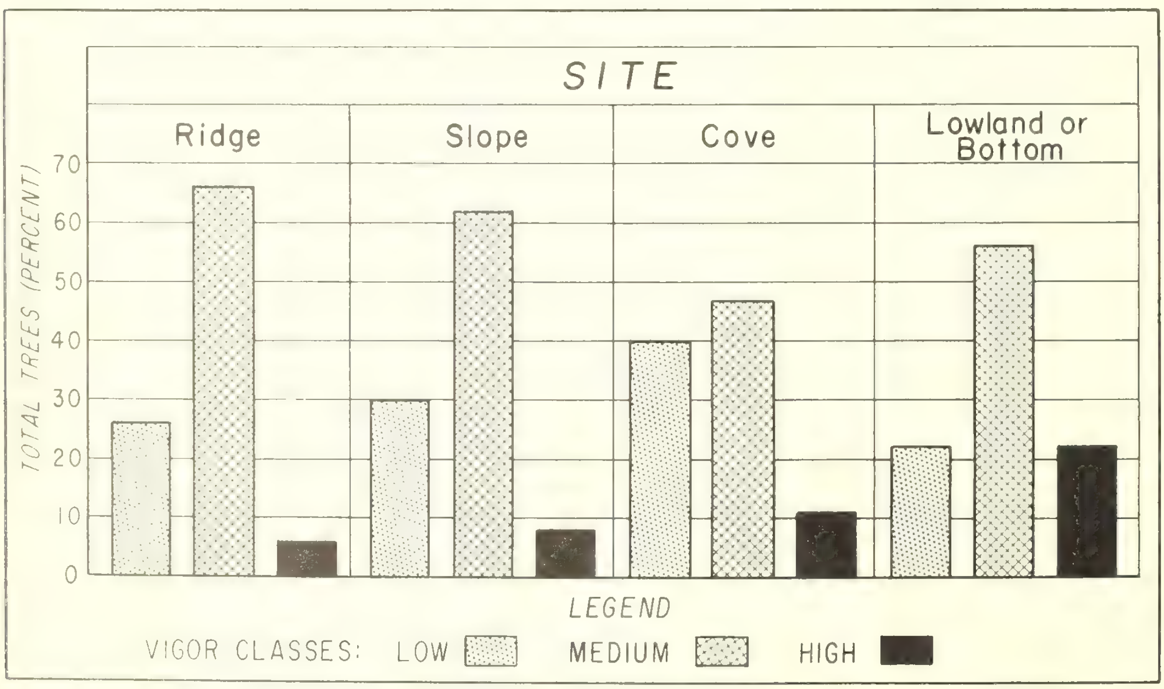


Figure 16.--Distribution of trees in the three vigor classes for each site.

THE MILL STUDY

Methods

As mentioned earlier, a bolter-saw study on small logs revealed some of the relations between external indicators and internal defect (figures 17 through 20). The purpose of the mill study itself was to measure and record defects in the larger merchantable Piedmont hardwoods in relation to visible external indicators. Because of limited resources and difficulties in following numbered logs through the mills within reasonable time, a "hot-log" study was not feasible.

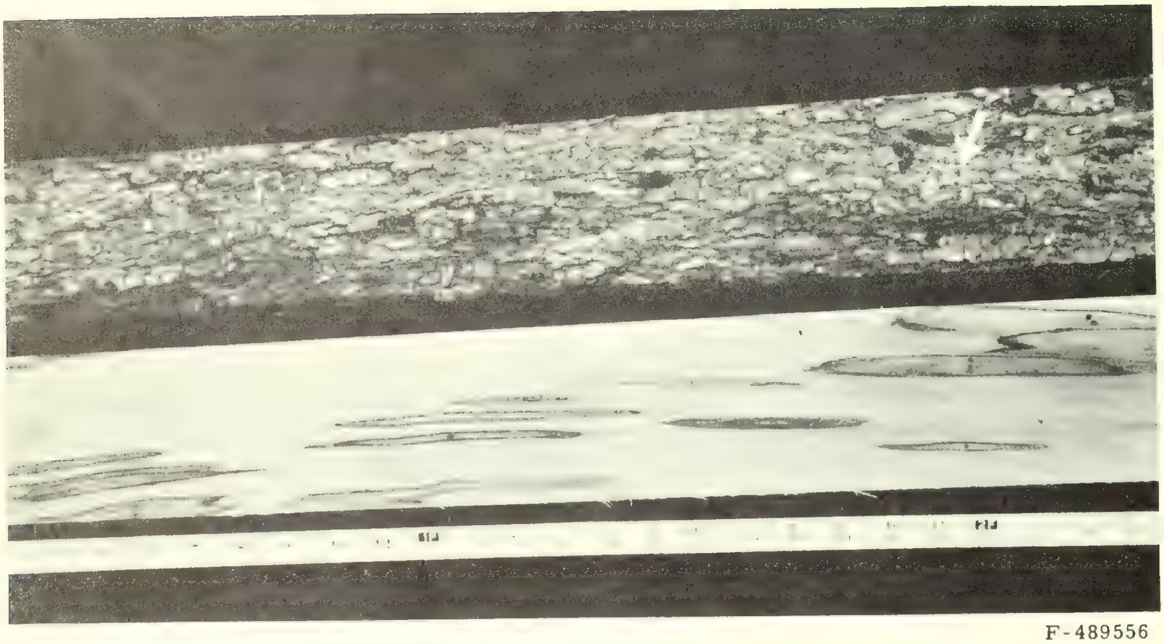
Data were taken at 18 mills cutting Piedmont hardwoods; these mills included small portable mills in the woods and large permanently located installations. Three mills were in North Carolina, four in South Carolina, and eleven in Georgia (fig. 1). It was impossible to make a systematic selection of mills from which to obtain data. Since the market for hardwood lumber was poor during the study, many mills were not logging or sawing hardwoods, or had shut down.

At each mill, 10 hardwood butt logs were examined on the log deck for external characteristics that might be indicative of type and extent of internal defect. The location of defects and other features on each log was plotted to scale on individual forms in the same manner as in the woods survey. Each log was numbered and the measured face marked for ready identification and orientation on the saw carriage. A few of the logs were so sawn that the character and extent of internal defect could neither be accurately measured nor correlated with the charted surface indicators. These logs were discarded as samples. Measurements of possible degrading defects on sawn logs were as follows: blemish character, depth to defect from surface, average length and width of defective or cull portion, and number of boards affected. Board thickness in all species was $1\frac{1}{8}$ inches except in hickory, which was cut into 2-inch boards.

Data were recorded from 160 butt logs of 23 species. The number of logs of some species was inadequate to yield representative data. After consolidating the most-commonly cut species into larger groups, data from a total of 138 logs of five major species or species groups, were analyzed. Each defect was considered as one observation. The reported averages were based upon the total number of all logs of a species.

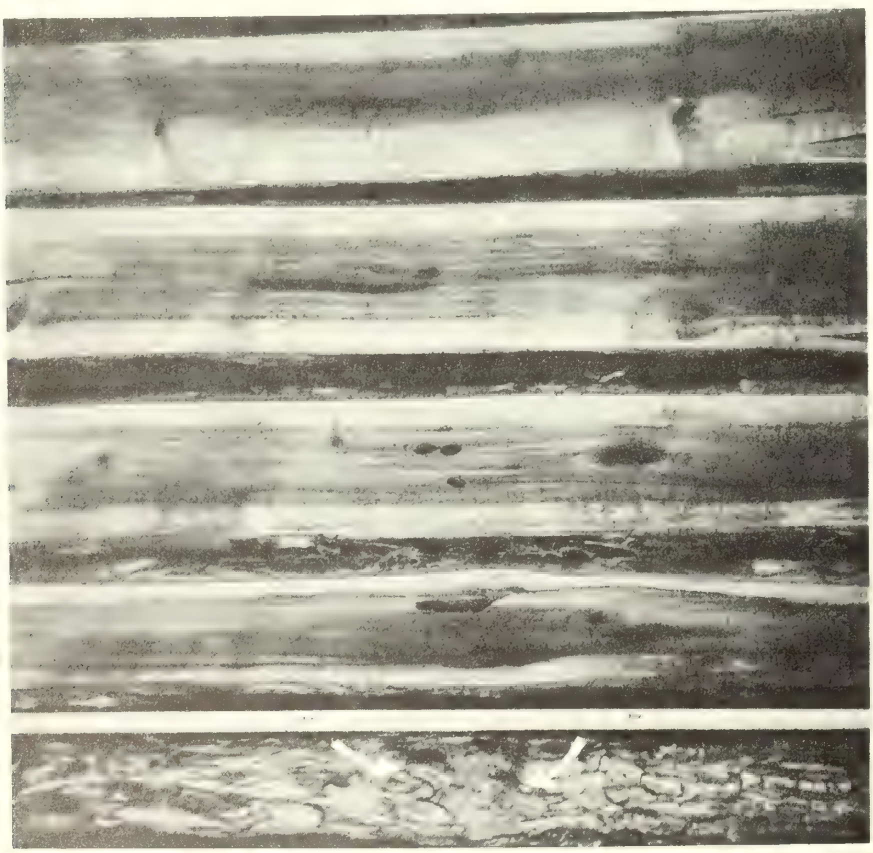
Results

The averages obtained from the mill study data are listed in table 6. They show that a given defect causes about the same loss regardless of species. All of the features listed were underlain by degrading blemishes in the part of the log where quality lumber should be obtained, and therefore are log defects. The comparatively large volume of cull per butt-rot indicator and other heart-rot indicator is outstanding.



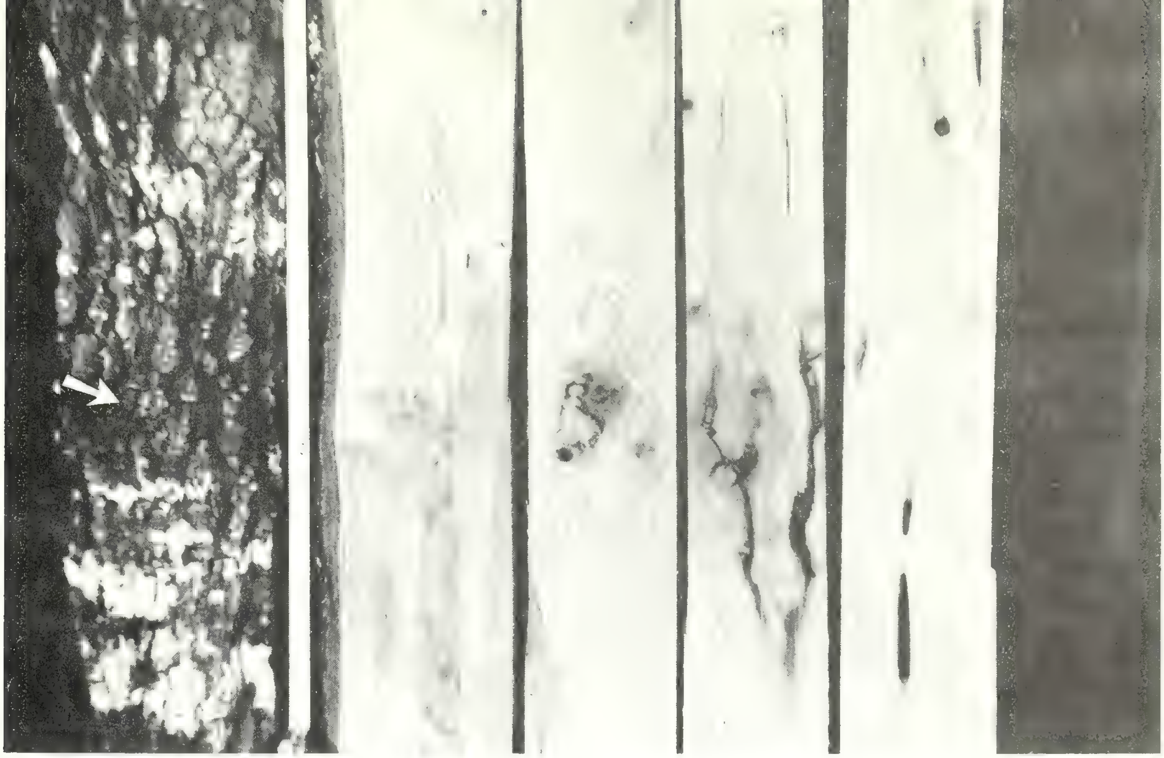
F-489556

Figure 17.--Ambrosia beetle defect in red maple. Arrow points to small external indicator of the defect.



F-489557

Figure 18.--Insect grub galleries in 6-inch sweetgum. Large swollen, puckered callus in bark indicates the type of defect.



F-489558

Figure 19.--Insect borer damage in 12-inch southern red oak. Arrow indicates swollen knot cluster and point of grub entry.

F-489559

Figure 20.--Limited internal extent of birdpeck in 12-inch yellow-poplar. Recent wound is indicated by clear line of callus union in bark scar, and shows only in first board.

Table 6. --Mill study measurements of defect extent beneath some common external indicators

D. b. h. Range (inches)	D. b. h. Mean (inches)	Defect indicator	Defects meas-ured	Depth to defect from surface: Minimum	Depth to defect from surface: Maximum	Depth to defect from surface: Mean	Length affected per defect: Range	Length affected per defect: Mean	Area affected per defect: Range	Area affected per defect: Mean	Boards affected: Range	Boards affected: Mean
		Type	Number	Inches					Square inches		Number	
		RED OAKS, 67 BUTT LOGS MEASURED										
11-40	20.4	Open or healed butt scar or butt bulge	22	1	14	7	4-144	50	16-1296	353	2-15	6
		Medium insect hole, swollen knot scar, or "puckered" scar	129	1	9	4	3-24	9	4-216	38	0-10	3
		Large insect hole, swollen knot scar, or "puckered" scar	41	1	9	4	3-36	14	3-432	77	0-10	3
		Other butt scar	10	1	8	4	12-84	39	63-540	227	0-2	1
		Stem scar	5	1	12	3	12-144	78	72-864	468	0-4	1
		WHITE OAKS, 30 BUTT LOGS MEASURED										
11-30	17.4	Open or healed butt scar or butt bulge	8	1	9	5	12-144	46	48-1440	439	2-11	6
		Small insect hole, "puckered" scar, or transverse bark split 1/	1	1	6	4	3-6	5	3-9	5	0-1	1
		Medium insect hole, "puckered" scar, or swollen knot scar	19	1	6	4	3-18	9	4-108	36	0-6	3
		Large insect hole, swollen knot scar, or "puckered" scar	22	1	10	5	4-18	11	12-144	64	0-7	3
		Other butt scar	6	1	4	2	30	30	180	180	0-8	2
		Stem scar	4	1	10	5	6-18	14	36-324	138	0-3	2
		SWEETGUM, 20 BUTT LOGS MEASURED										
12-24	16.5	Open or healed butt scar or butt bulge	12	1	7	3	24-108	63	96-864	495	3-8	6
		YELLOW-POPLAR, 12 BUTT LOGS MEASURED										
10-32	19.9	Open or healed butt scar or butt bulge	8	3	13	7	12-96	47	48-864	301	3-9	5
		Medium insect hole, swollen knot scar, or "puckered" scar	21	1	5	3	3-12	5	3-48	17	0-4	2
		HICKORIES, 9 BUTT LOGS MEASURED										
17-26	21.8	Birdpeck--small pecked-out holes with callus at bottom	2/ 1	1	6	4	6-7	6	6-21	15	0-1	1
		Large insect hole, swollen knot scar, or "puckered" scar	8	3	11	6	3-18	9	5-108	37	1-5	3

1/ Number per 5-square-inch area. Total not counted because of large number.

2/ Averaging one or less per square foot of surface area. Hickory logs with heavy birdpeck defect were not accepted at the mill visited, for lumber from such logs would be useless for the products being manufactured--ski blanks, tool handle stock, picker sticks, and other similar items.

The following example illustrates the practical application of the data in table 6. The scaler examining a 20-inch red oak log with large insect-damage indicators can expect an average of one unaffected board before reaching the defect (fig. 19), each of which will cause an average loss of 14 inches in clear length, and will affect an average of 3 boards inward.

Detection of External Indicators of Defect

Most external indicators of defect are easily detected during quality appraisal before a sale. However, those associated with insect damage are most commonly overlooked or incorrectly identified and may, therefore, be responsible for a large share of erroneous estimates. As an illustration, at one of the portable mills in the lower Piedmont section of Georgia, the operator stated that the logs being cut at his mill during this study were sawing out far below the estimate of the appraiser. The logs measured were oak, averaging 25 inches in diameter $3\frac{1}{2}$ feet above the butt cut. After the logs had been sawn, it was found that excluding knots, 86 percent of the degrading defect noted beneath external indicators was a result of insect attack. The remaining 14 percent resulted from butt and heart rot, beneath readily noticeable butt scars. Obviously, the timber appraiser had not properly evaluated the insect defect indicators present. The usual small size of external signs of insect damage makes them easily overlooked, but their importance in an evaluation of timber cannot be overemphasized.

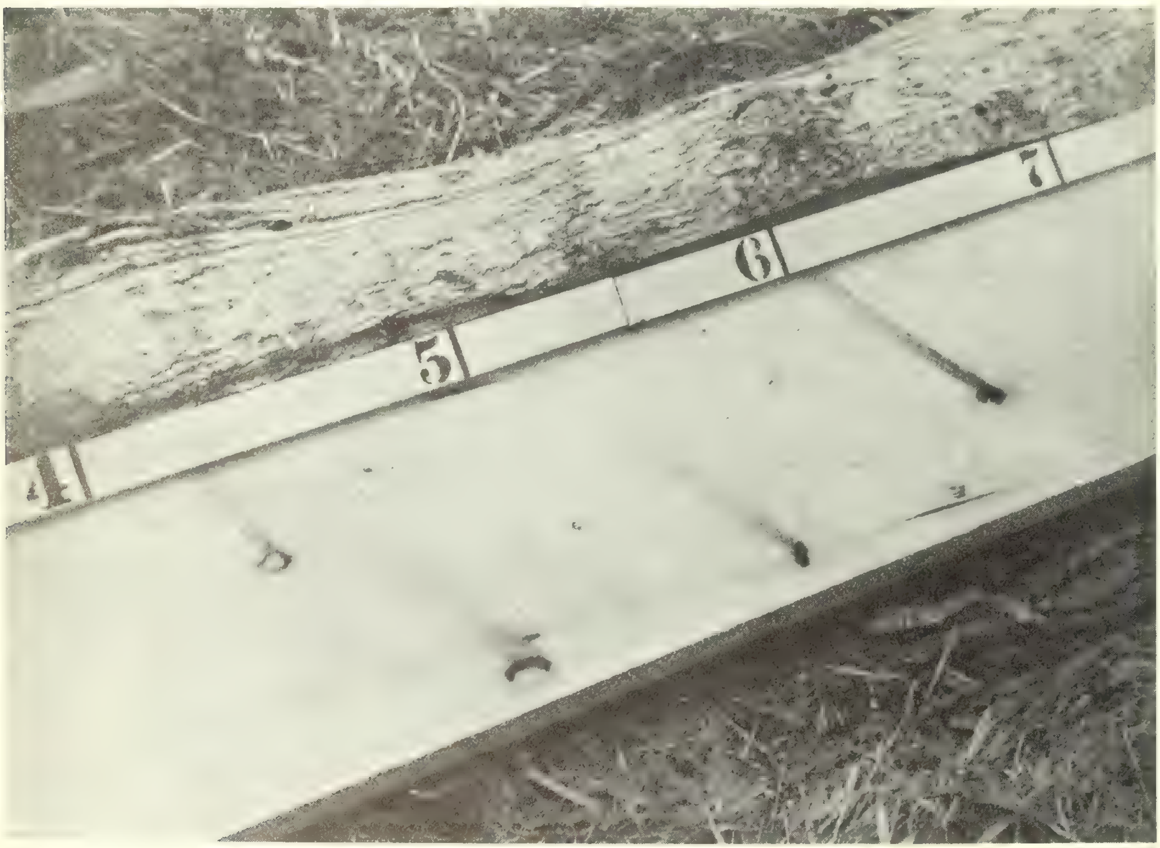
The internal extent and character of some of the most common and serious defects found beneath their external indicators are illustrated and described in figures 21 through 26.

F-489560

Figure 21.--Rotten branch stub in 18-inch swamp white oak, with rot in heart board extending 4 feet lengthwise in trunk.

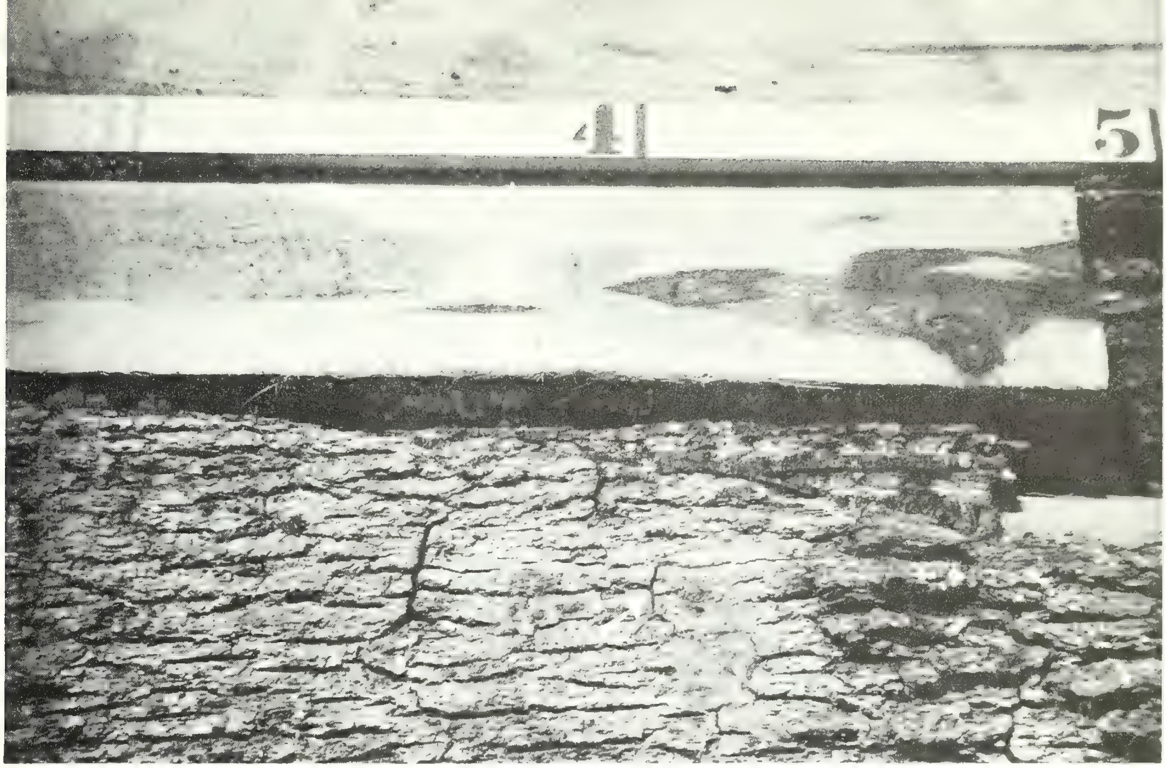
F-489561

Figure 22.--Large insect borer damage in 11-inch white oak, showing gallery in second 2-inch board beneath slab.



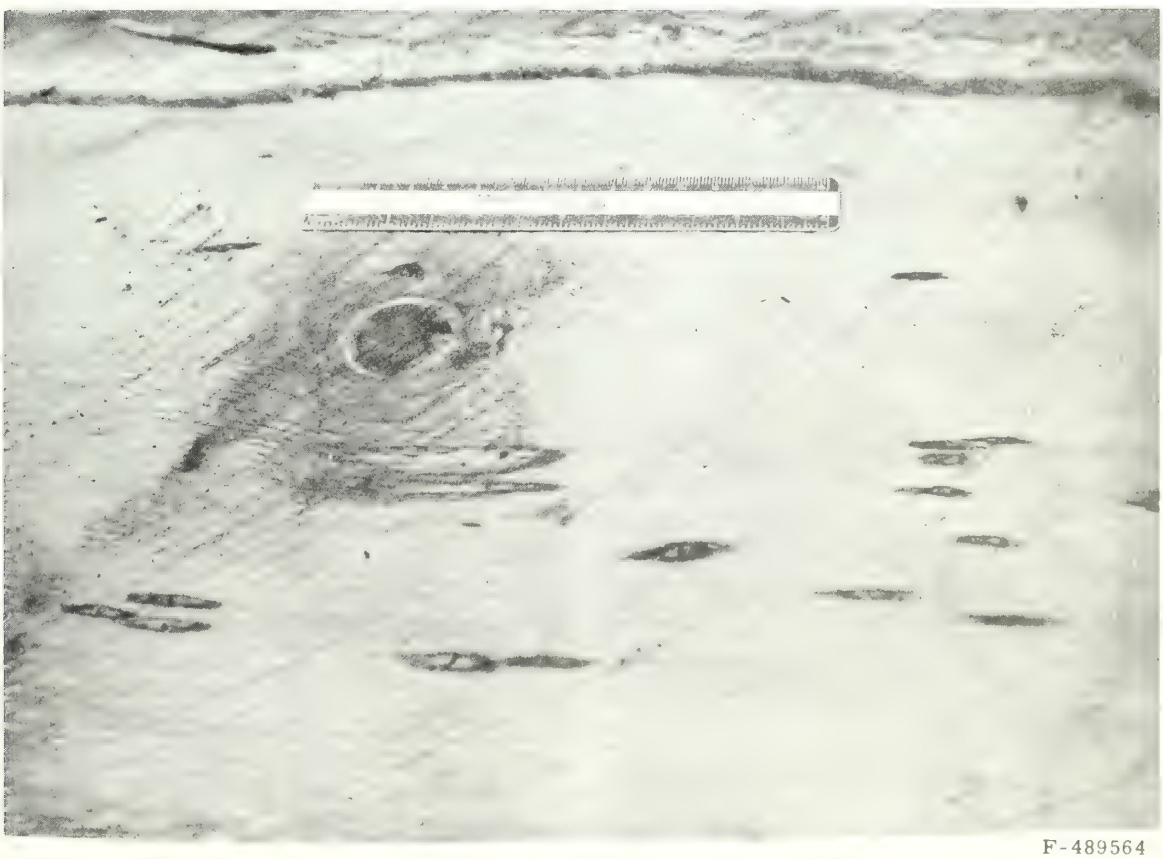
F-489562

Figure 23.--Insect borer entry at knot scars in 24-inch redbay. The defects appear in the second 1-inch board beneath the slab.



F-489563

Figure 24.--Ambrosia beetle defect in 20-inch post oak. Holes and stain illustrated in third 1-inch board. Arrow points to indicators in slab--small swollen transverse bark splits.



F-489564

Figure 25.--Shot-hole borer defect in 30-inch post oak, confined in this log to the slab and outer sapwood. Log face above was flattened, with small swollen transverse bark splits.

F-489565

Figure 26.--Ambrosia beetle defect in 14-inch yellow-poplar, shown in first two 1-inch boards beneath slab. Arrow points to the external indicator, a small hole in a swollen area in the bark.

CONCLUSIONS

Of all of the measured factors that influence present incidence of defect, or have a bearing on the development of defect in Piedmont hardwoods, probably the most important is the small average size of the trees. This is undoubtedly a reflection of their young age rather than low vigor, for approximately 60 percent of the trees studied were of medium vigor, and 11 percent of high vigor. It seems most probable that as the trees increase in size and attain dominance, the incidence of the most prevalent defects, epicormic and adventitious branching and small knots, should decline. This interpretation is obtained from figure 14,

which shows that the highest loss from epicormic and adventitious branching is in the 14-inch diameter class, the average diameter class for all trees. A sharp drop in such loss occurred in larger trees. In addition, figure 14 shows that the trees in the dominant crown class have a lower percent loss in clear 2-foot cuttings than those in the other crown classes. Since epicormic and adventitious branching have a tendency to persist up to 16 inches d. b. h., it would seem that a considerable increase in diameter will often be necessary before many trees can be considered satisfactory for production of factory grade lumber.

Although the survey shows that the majority of the trees studied were of low quality, it also shows that the great majority of the trees are relatively sound, as evidenced by the low percentage of trees affected with stem disease. This low percentage of butt cull reflects improved fire protection.

Most of the Piedmont hardwoods today are in second-growth, unmanaged stands. If such stands are protected from fire and overgrazing, and if proper management and harvesting measures are practiced, defects of all types should be substantially reduced.

Good management includes favoring codominant or dominant trees of good form for sawtimber, and eliminating, in intermediate cuts, the large number of trees that today are contributing to the over-all poor quality of Piedmont hardwoods because of their extreme knottiness and high incidence of sweep and crook. Intensive protection of stands from fire and overgrazing would further contribute to better quality by reducing the number of fire scars and other wounds which favor insect and disease attack. The effects of site upon tree vigor are well known and are reaffirmed in figure 16. The relationships illustrated in figure 14 for loss of clear cuttings due to epicormic and adventitious branching, and in figure 15 for losses due to insect defects as influenced by vigor, basal area, and site, may provide bases for further experiments to determine methods for minimizing these defects. Considering the data as a whole, it may be assumed that the more vigorous trees have the least loss of clear cuttings from insect defects. In stands of high basal area there is less loss of clear cuttings from insect defects, but greater loss from epicormic and adventitious branching. A further summary of the data, including all measured influences, shows that the best Piedmont hardwoods are growing in lower slope or cove sites, and with basal areas of 140 to 150 square feet per acre.

Based on results from the mill study, re-emphasis should be placed upon the importance of closely scrutinizing standing timber when doing stand improvement work, as well as when making timber appraisals. Only by this means is it possible to detect the insignificant-appearing insect borer scars that cause a major part of the defect in Piedmont hardwoods.

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Agriculture - Asheville

Silvical Characteristics of Swamp Chestnut Oak

by

Thomas Lotti

Station Paper No. 110

February 1960

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Southeastern Forest Experiment Station
Asheville, North Carolina

Silvical Characteristics of Swamp Chestnut Oak

(Quercus michauxii Nutt.)

by

Thomas Lotti
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Swamp chestnut oak, also known as cow oak or basket oak, is found along the Atlantic Coastal Plain from New Jersey south to central Florida and eastern Texas, and north in the Mississippi Valley to southeastern Missouri, central Illinois, southwestern Ohio, and eastern Kentucky (5) (fig. 1).

HABITAT CONDITIONS

CLIMATIC

Swamp chestnut oak grows in a humid temperate climate characterized by hot summers, mild and short winters, and no distinct dry season (9). Through the main part of the tree's commercial range, the growing season averages from 200 to 250 days, with an average annual temperature from 60° to 70° F. and an average annual precipitation from 50 to 60 inches. Within this same area the average annual maximum temperature is about 100° F. and the average annual minimum approximates 15° F. About half the rainfall occurs during the period of April to September. The average noonday relative humidity in mid-July is about 60 percent (10).

EDAPHIC AND PHYSIOGRAPHIC

The species is widely distributed on the best well-drained loamy first bottom ridges, but it is principally found on well-drained silty clay and loamy terraces and colluvial sites in the bottomlands of both large and small streams (6).

BIOTIC

Swamp chestnut oak is included in the swamp chestnut-cherrybark oak type, which varies widely in composition (8). Often swamp chestnut oak and cherrybark oak (Quercus falcata var. pagodaefolia) are only indicator species, although they may be the most abundant of the oaks which are predominant. Other prominent hardwoods are white ash (Fraxinus americana), shagbark hickory (Carya ovata), shellbark hickory (Carya laciniosa), mockernut hickory (Carya tomentosa), and bitternut hickory (Carya cordiformis). Chief

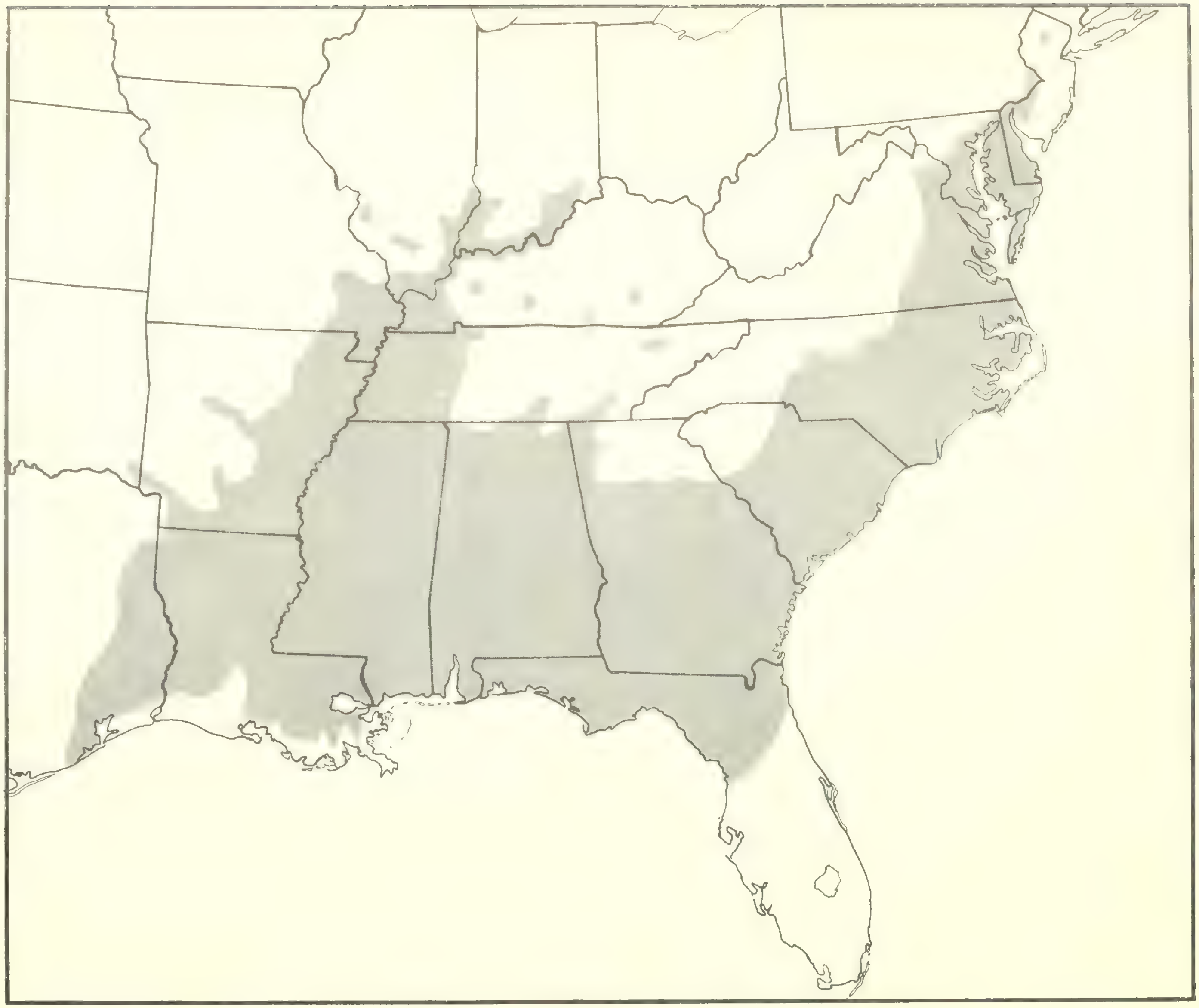

Figure 1. --Botanical range of swamp chestnut oak.

associates are white oak (Quercus alba), (fig. 2), Delta post oak (Quercus stellata var. mississippiensis), Shumard oak (Quercus shumardii), and blackgum (Nyssa sylvatica). Occasionally sweetgum (Liquidambar styraciflua) is important on first bottom ridges. Minor associates include willow oak (Quercus phellos), water oak (Quercus nigra), southern red oak (Quercus falcata), post oak (Quercus stellata), American elm (Ulmus americana), winged elm (Ulmus alata), swamp hickory (Carya leiodermis), nutmeg hickory (Carya myristicaeformis), southern magnolia (Magnolia grandiflora), yellow-poplar (Liriodendron tulipifera), American beech (Fagus grandifolia), sassafras (Sassafras albidum), loblolly pine (Pinus taeda), and spruce pine (Pinus glabra).

Among the non-commercial trees or plant associates are devils-walking-stick (Aralia spinosa), painted buckeye (Aesculus sylvatica), pawpaw (Asimina triloba), American hornbeam (Carpinus caroliniana), stiff cornel dogwood (Cornus foemina), dwarf palmetto (Sabal minor), Coastal Plain willow (Salix caroliniana), snowbell (Styrax americana), arrowwood (Viburnum dentatum) and possumhaw (Viburnum nudum) (4).

LIFE HISTORY

SEEDING HABITS

Flowering and fruiting. --The tree's flowers are unisexual, appearing with the leaves (mostly April to May), the staminate in slender hairy catkins 2 to 3 inches long, the pistillate in short-stalked, few flowered spikes (3).

The fruit is an acorn, a solitary or paired nearly sessile nut $\frac{3}{4}$ to $1\frac{1}{4}$ inches wide and 1 to $1\frac{1}{2}$ inches long, and a lustrous brown; the cup is thick, bowl-shaped, with wedge-shaped scales, enclosing up to one-third of the nut (3) (fig. 3). Ripening occurs from September to October of the first year and seedfall is during this period (11). Damage from nut weevils is heavy in many localities, at least in poor to fair seed years. Curculio pardalis, Curculio rectus, Conotrachelus naso, and Conotrachelus posticatus are among the weevils attacking swamp chestnut oak acorns. Blemishes on the acorn shell, ranging in size from a pin point to large blotches, usually indicate the presence of weevil activity.

Seed production and dissemination. --Seed bearing begins when trees are about 25 years of age, with optimum production commencing at about 40 years. Good crops occur at intervals of 3 to 5 years, with poor to fair production in between. A freeze in April after flower buds opened resulted in a complete crop failure in the Carolinas in 1955. Cleaned seed will range from 55 to 195 acorns per pound, averaging about 100 (11). Dissemination depends largely on hoarding activity of animals, especially squirrels. Gravity may be of minor importance on the steeper terrace margins.

VEGETATIVE REPRODUCTION

Swamp chestnut oak is reported to sprout effectively (6), but this is not generally considered a dependable means for obtaining desirable natural regeneration.

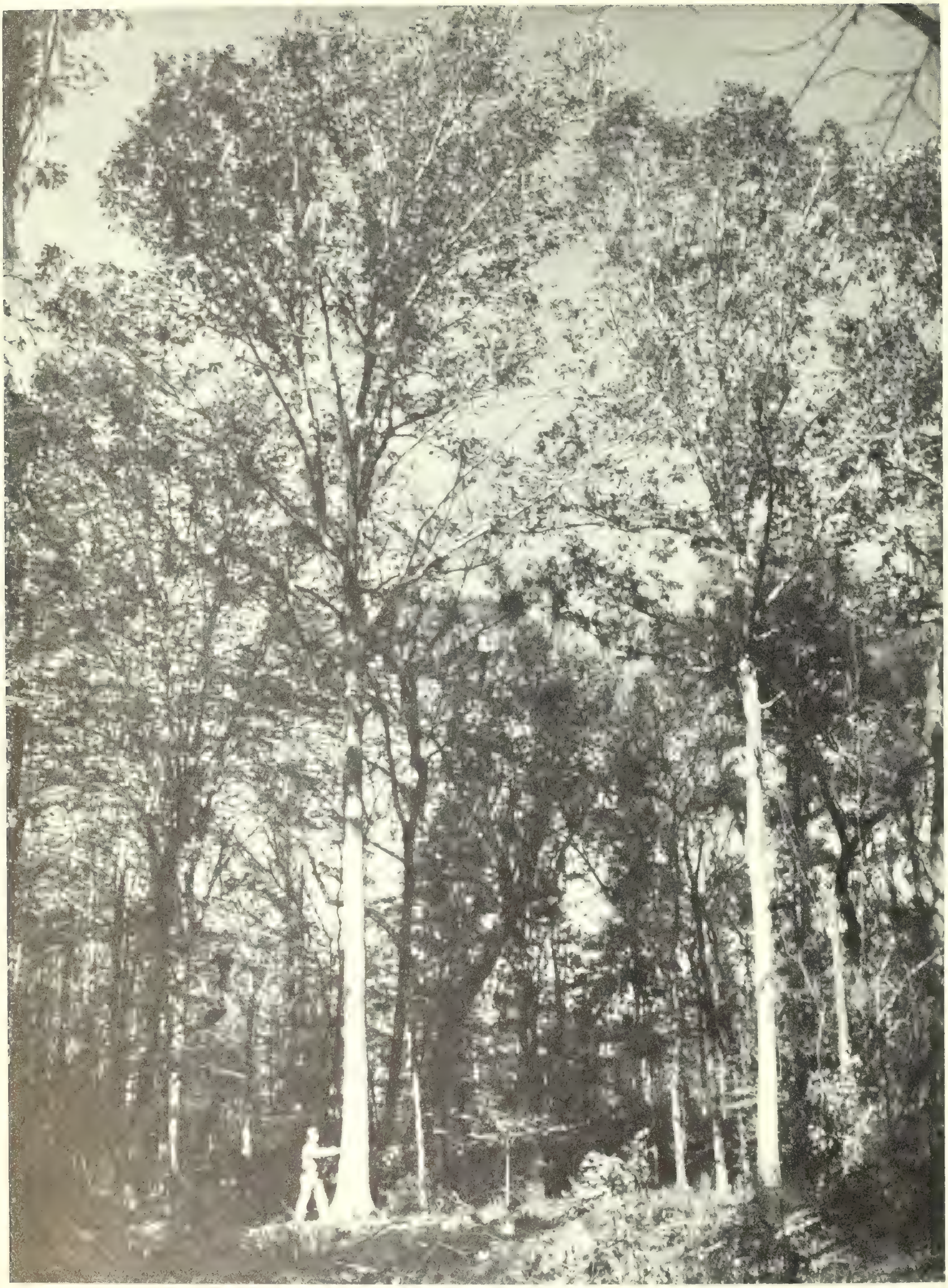

Figure 2. --Swamp chestnut oak (left) and white oak (right), each about 50 years old, as found in the swamp chestnut-cherrybark oak type on the Santee Experimental Forest.

Figure 3. --Typical bark, fruit, twig and bud, and leaves of swamp chestnut oak.

SEEDLING DEVELOPMENT

As the nut is highly palatable and much sought after by animals, regeneration from seed is often very sparse. Propagation by direct seeding or with nursery stock has not been adequately explored.

Studies in progress at the Santee Experimental Forest in the South Carolina Coastal Plain point to good survival and early growth of swamp chestnut oak from planted acorns and 1-0 nursery stock on sandy loam soils in the bottomland of smaller streams.

Limited tests indicate a germinative capacity averaging 87 percent and a 30-day period of germination (11). Like most of the white oaks, germination begins soon after seedfall with little or no period of dormancy. The best seedbed is a moist, well-drained, sandy loam with a light cover of leaves or litter.

The species is classed as moderately intolerant but is easily established in openings (6).

As is common to most bottomland hardwoods, the sunlight necessary for seedling growth induces heavy competition from annual weeds, vines, briars, and brush which limit early development of the swamp chestnut oak unless it is released by weeding.

SAPLING STAGE TO MATURITY

Swamp chestnut oak usually ranges from 60 to 80 feet in height, with a trunk diameter of 24 to 36 inches; rare specimens may attain heights up to 120 feet and diameters of 7 feet (3). Diameter growth is classed as medium to good, averaging 2 to 4 inches in 10 years for dominant and codominant trees on average or better sites (6). In the absence of pure natural stands of swamp chestnut oak, areawise volume and yield values are not available. In mixtures with other hardwoods, a total volume in excess of 8,000 board feet per acre is classed as a heavy sawtimber stand; a heavy pole stand is considered to have in excess of 175 total stems per acre ranging from 5 to 11 inches d. b. h. (6).

The primary uses of swamp chestnut oak are essentially the same as white oak, such as face veneer, tight cooperage, factory lumber, ties, and timbers. Compared with white oak it has a coarser grain and wider sapwood due to more rapid growth; both features slightly handicap swamp chestnut oak for face veneer and tight cooperage (6).

Swamp chestnut oak timber is unusually sound, clear, and dependably uniform. One of its chief defects is a tendency toward sap limbs above the first log. Bird peck is occasional. Hidden defects are uncommon and it usually cuts out as well as it looks (7).

Among the more important wood-decaying fungi attacking swamp chestnut oak are species of Fomes, Polyporus, and Stereum. Oak leaf blister, caused by Taphrina caerulescens, is common some years, as is oak anthracnose which results from infection by Gnomonia veneta. Oak wilt, caused by Ceratocystis fagacearum, may also attack this species (1).

The list of insects affecting the oaks is almost endless. Among the most important which probably attack swamp chestnut oak, in addition to the aforementioned nut weevils, are the following (2):

Defoliators. --June beetles (Phyllophaga spp.), orange-striped oakworm (Anisota senatoria), canker worms (Alsophila pometaria) and (Paleacrita vernata), forest tent caterpillar (Malacosoma disstria), yellow-necked caterpillar (Datana ministra), variable oak leaf caterpillar (Heterocampa manteo), and the red-humped oakworm (Symmerista albicosta).

Borers attacking healthy trees. --Red oak borer (Romaleum rufulum), attacking the cambium and outer sapwood; carpenter worms (Prionoxystus spp.), attacking both the heart and sapwood; and the columbian timber beetle (Corthylus columbianus), which works in the sapwood.

Borers attacking weakened trees. --Two-lined chestnut borer (Agrilus bilineatus), found in the cambium, and tile-horned prionus (Prionus imbricornis), found in the roots.

Borers attacking dying trees. --Oak timberworm (Arrhenodes minuta).

Scales. --Pit making oak scale (Asterolecanium variolosum), which kills reproduction and tops on older trees.

Galls. --Gouty oak gall (Callirhytis punctata), horned oak galls (Callirhytis cornigera) and (Andricus clavigerus).

Leaf Miners. --Basswood leaf miner (Baliosus ruber).

RACES AND HYBRIDS

Reported natural hybrids (5) are Quercus beadlei Trel. (Q. alba X Q. michauxii) and Quercus byarsii Sudw. (Q. macrocarpa X Q. michauxii).

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Agriculture - Asheville

Silvical Characteristics of Bitternut Hickory

by

Thomas C. Nelson

Station Paper No. 111

March 1960

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Southeastern Forest Experiment Station
Asheville, North Carolina

Silvical Characteristics of Bitternut Hickory

(Carya cordiformis (Wangenh.) K. Koch)

by

Thomas C. Nelson
Southeastern Forest Experiment Station

Bitternut hickory (Carya cordiformis (Wangenh.) K. Koch), sometimes called swamp hickory or pignut (10), is the only member of the pecan group (Apocarya) common to the northeastern United States and is probably the most abundant and uniformly distributed of the hickories. It is found in all of the eastern United States, except the northern parts of Michigan and Wisconsin, and on the South Atlantic and Gulf Coastal Plains (7) (fig. 1). It is common from southern New England west to Iowa and from southern Michigan south to Kentucky (4). Its range extends farther west than any other hickory species except shagbark (5) and farther north than other hickories. Bitternut hickory, marketed as "pecan," finds use in tool and implement handles and flooring. The lower grades are used in pallets (18).

HABITAT CONDITIONS

CLIMATE

Bitternut hickory grows in a climate classified as humid (16). Generally, the mean annual precipitation varies from 25 to 50 inches within the range of the species, except for a small area in the Southern Appalachians where 80 inches is not uncommon. In the northern portion of the species range, snowfall averages 80 inches per year; at the southern extreme of the range, it rarely snows (9).

Average annual temperatures range from 40° to 55° F.; average July temperatures from 56° to 80°; and average January temperatures from 15° to 50°. Extremes of 115° and -40° have been recorded within the range. Bitternut is seldom found in areas with less than 120 days or more than 240 days of average growing season (9).

EDAPHIC AND PHYSIOGRAPHIC

The habitat of bitternut hickory varies with relation to the portion of its range under consideration. In the northern part of its range, bitternut hickory occurs on a variety of sites. Otis (11), in describing its habitat in Michigan, states that the species "prefers a rich, loamy or gravelly soil; low wet woods; along the borders of streams; but also found on high, dry uplands."

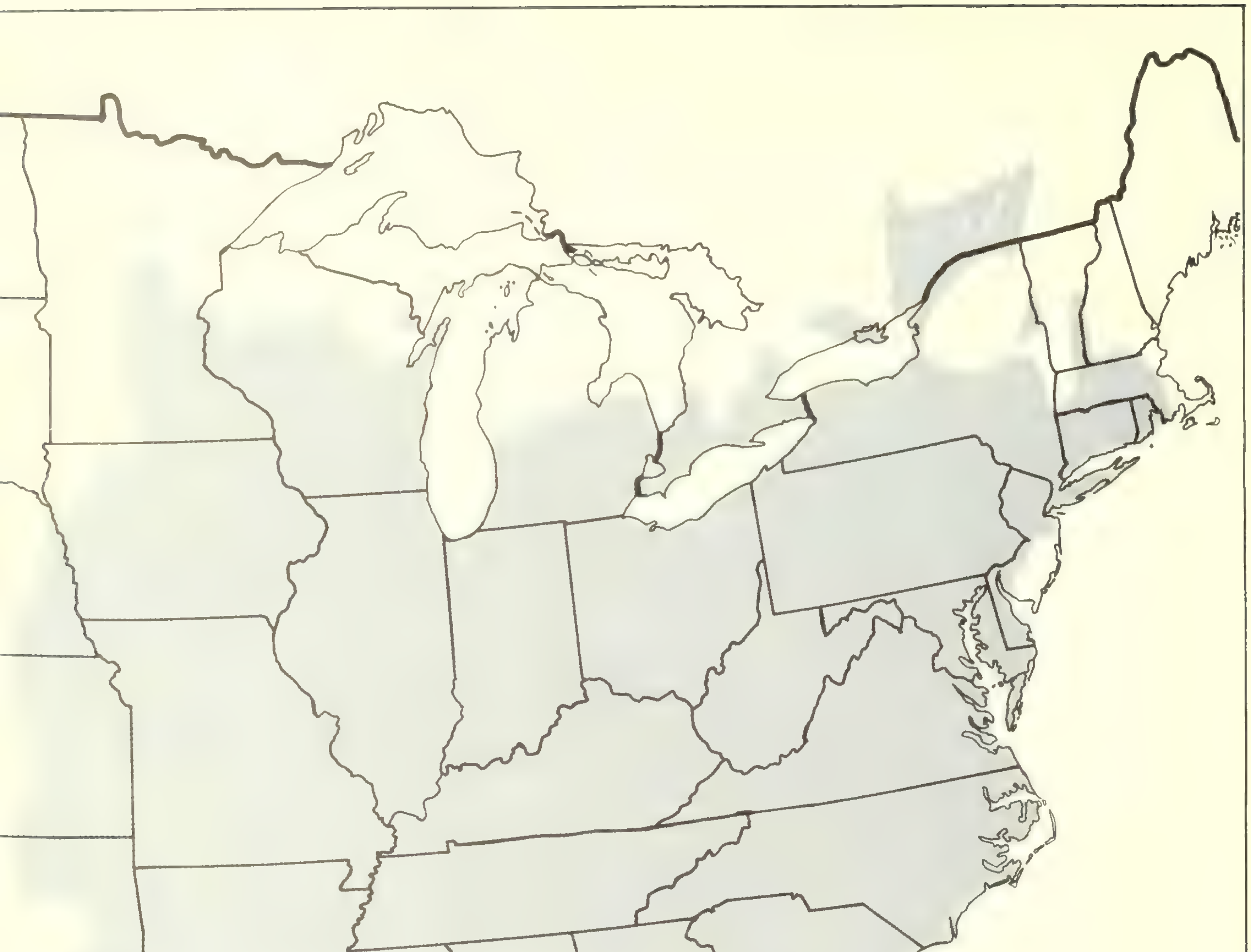

Figure 1. --Botanical range of bitternut hickory.

In the southern portion of its range, bitternut is more restricted to moist sites than in the northern part. It reaches its largest size on the rich bottom lands of the lower Ohio basin (13). In the southeastern portion of its range, it occurs only on overflow bottoms (3) (fig. 2). However, in the southwestern part of its range, bitternut is common on the poor, dry, gravelly soil of the uplands (13).

Bitternut is absent from the mountain forests of northern New England and New York (13), and is not found at the higher elevations in the Appalachians.

BIOTIC

Bitternut hickory is a major component of two forest cover types and is a secondary species in another. In the northern part of the white oak-red oak-hickory type (type 52), bitternut is often the hickory species which forms this type in combination with various oaks. In the South, bitternut is often a prominent species in the swamp chestnut oak-cherrybark oak type (type 91). Bitternut hickory, black oak (Quercus velutina), northern red oak (Quercus rubra), bur oak (Quercus macrocarpa), shagbark hickory (Carya ovata), white ash (Fraxinus americana), bigtooth aspen (Populus grandidentata), and yellow-poplar (Liriodendron tulipifera) are associates in the white oak type (type 53). The forest types in which bitternut hickory is a major component are climax or permanent types.

Because it occupies various site conditions throughout its geographical range, its associates are varied. An example of its associates in the northern portion of its range is given by Gordon (6). In northern Indiana, principal associates in the upland oak forest include white oak (Quercus alba), red oak, black oak, shingle oak (Quercus imbricaria), shagbark hickory, and pignut hickory (Carya glabra). Secondary associates are red maple (Acer rubrum), black cherry (Prunus serotina), and sassafras (Sassafras albidum). Bitternut is a minor associate of the "mixed mesophytic" forest of that region. However, it is conspicuously absent in the description of species on the poorly drained and bottom land sites of northern Indiana.

Braun (5) quotes Akerman on the associates of bitternut hickory in eastern Virginia. On the ravine slopes and the slopes from the uplands to the stream beds, bitternut hickory is associated with beech (Fagus grandifolia), yellow-poplar, elm (Ulmus spp.), sycamore (Platanus occidentalis), sweetgum (Liquidambar styraciflua), white oak, red maple, black walnut (Juglans nigra), and butternut (Juglans cinerea).

In the southern bottom land hardwoods, bitternut is associated with swamp chestnut oak, cherrybark oak (Quercus falcata var. pagodaefolia), white ash, shagbark hickory, shellbark hickory (Carya laciniosa), mockernut hickory (Carya tomentosa), white oak, Delta post oak (Quercus stellata var. mississippiensis), Shumard oak (Quercus shumardii), and black gum (Nyssa sylvatica). Sweetgum may occasionally be of high importance in association with bitternut. Minor associates include willow oak (Quercus phellos), southern red oak (Quercus falcata), post oak (Quercus stellata), American elm

Figure 2.--Forest-grown bitternut hickory, Oglethorpe County, Georgia. This tree, standing in the Oconee River bottom lands, is approximately 45 years old, 103 feet tall, and 20 inches d. b. h.

(Ulmus americana), winged elm (Ulmus alata), swamp hickory (Carya leiodermis), nutmeg hickory (Carya myristicaeformis), southern magnolia (Magnolia grandiflora), yellow-poplar, and American beech (Fagus grandifolia) (14).

LIFE HISTORY

SEEDING HABITS

Flowering and fruiting.--The male and female flowers are borne in separate flowers on the same plant (monoecious). Catkins of male flowers are from 3 to 4 inches long, and are usually produced on branches of the previous year. Female flowers are $\frac{1}{2}$-inch in length and covered with yellow, dense pubescence (13).

Depending upon latitude and weather, the flowers bloom in April or May; the fruit ripen in September and October, and are dispersed from September through December (17) (fig. 3).

Seed production.--Bitternut hickory does not produce seed until the tree is approximately 30 years of age. Optimum seed production extends from 50 to 125 years. Trees over 175 years seldom produce good seed crops (17).

Good seed crops appear at 3- to 5-year intervals. Light seed crops are borne in the intervening years (17). Bitternut hickory seed is estimated to be from 70 to 85 percent viable (15).

Seed dissemination.--Seed dissemination is almost entirely by gravity, since the fruit is claimed to be generally distasteful to wildlife (19).

VEGETATIVE REPRODUCTION

Boisen and Newlin (4) state that bitternut hickory is the best sprouter of the northern species of hickory. The average height of dominant 1-year-old sprouts was 4.7 feet. Sprouts may grow from the stump, the root collar, and the root. Most of the sprouts from sapling and pole-size trees are root collar sprouts, and those from sawtimber-size trees are mostly root suckers. Sprouts from the stumps are usually less numerous than either root collar sprouts or root suckers.

SEEDLING DEVELOPMENT

Establishment.--Hickories, in general, require a moderately moist seedbed (20) for satisfactory seed germination. Bitternut probably can tolerate a more moist seedbed than most of the other species. It is one of the hickories least susceptible to frost (4).

Early growth.--No information is available on early seedling growth; however, Boisen and Newlin (4) reported the average bitternut on red clay soil had an 11-inch taproot at the age of 1 year.

gure 3. --Typical bark, twig and bud, leaves, and fruit of bitternut hickory.

SAPLING STAGE TO MATURITY

Growth and yield.--Second-growth bitternut hickory on a good site in the Ohio Valley reaches the following average heights and diameters (4).

Age (Years)	Height (Feet)	D. b. h. (Inches)
10	10	2.0
20	24	4.0
30	40	6.0
40	52	7.6
50	62	9.2
60	69	11.4
70	--	13.0

Bitternut has a tendency to prune itself more readily than the other hickories. The proportion of sapwood to heartwood is characteristically low; sapwood is seldom over $1\frac{1}{2}$ inches wide or more than 25 years old (4).

Reaction to competition.--The hickories, in general, were classified as intolerant by Baker (1), although bitternut seems to have a higher seedling tolerance on overflow bottoms than most of its associates.

Principal enemies.--When young, bitternut hickory is very easily damaged by fire (19), and is susceptible to fire-damage at all ages. Although bitternut probably is host to a number of stem and root rots, none are known to be particularly damaging. However, like all hardwoods, a number of heart-rot fungi will cause progressive decay after they gain entry through wounds, particularly those wounds caused by fire. It is host to several leaf and twig fungi: anthracnose (*Gnomonia caryae*), witches'-broom (*Microstroma juglandis*), and scab (*Cladosporium effusum*).

Bitternut hickory is attacked by the hickory bark beetles (*Scolytus quadrispinosus*), especially in drought years. Ambrosia beetles (*Platypus compositus*) are common on logs (2). Younger trees are attacked by the hickory twig girdlers, *Oncideres cingulatus*, *Oncideres texanus*, and *Oncideres pustulatus* (8).

RACES AND HYBRIDS

There is no evidence thus far to show the existence of geographic races in bitternut hickory.

Three naturally occurring hybrids of bitternut hickory are recognized: *Carya* X *brownii* Sarg. (*Carya cordiformis* X *illinoensis*); *Carya* X *demareei* Palmer (*Carya cordiformis* X *glabra*); and *Carya* X *laneyi* Sarg. (*Carya cordiformis* X *ovata*) (9, 12).

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